SURFACE IGNITION IN A STEADY-FLOW APPARATUS

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Submitted in partial fulfillment of the
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June, 1957

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ABSTRACT

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Submitted to the Department of Aeronautical Engineering on May 20, 1957, in partial fulfillment of the requirements for the degree of Master of Science in Aeronautical Engineering.

An experimental study is made of the temperature of a hot surface required to ignite ethanol-air mixtures of different fuel-air ratios in steady flow. The mixture at a controlled free-stream velocity, density and temperature flows over a four-inch heated surface in the test section. Temperature of the surface is increased slowly until ignition occurs. The effect on ignition temperature of varying fuel-air ratio is determined at velocities of 35 and 50 ft per sec. The free-stream density and temperature were held constant at 0.0575 lbs per cu ft. and 634°R respectively. In addition, the variation of ignition temperature with the parameter $V/\rho_o L$ was investigated for the stoichiometric fuel-air ratio.

The results reveal that, at a mixture density of 0.0575 lbs per cu ft., the minimum temperature required for ignition remains essentially constant at fuel-air ratios near the stoichiometric value. For a free-stream velocity of 35 ft per sec., the temperature required is approximately 2425°R from 0.73 to 1.65 times the stoichiometric fuel-air ratio. When operating at 50 ft per sec., the temperature required is approximately 2470°R over a smaller range of 0.77 to 1.32 times the stoichiometric fuel-air ratio. In both cases the temperature increases sharply as fuel-air ratios fall below the lower end of the constant range, and gradually increase as they go above the higher end.

It is verified that surface temperature required for ignition plotted versus $V/\rho_o L$ is a concave downward curve of positive slope. Lower temperatures than previously reported at the same values of $V/\rho_o L$ were obtained. The results of these previous studies, where nozzle temperature was maintained at approximately 580°R, were reproduced.

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35890

Cambridge, Massachusetts
May 20, 1957

Professor Leicester F. Hamilton
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

A thesis entitled, "Surface Ignition in a Steady-Flow Apparatus" is herewith submitted in partial fulfillment of the requirements for the degree of Master of Science in Aeronautical Engineering.

Respectfully,

Cecil J. Kempf

Joseph L. Wosser, Jr.

ACKNOWLEDGMENT

The basis for the experimental work described herein is the theory proposed by Professor T. Y. Toong. The firm foundation of work previously accomplished under his supervision in this field inspired the authors to continue the work. His guidance and suggestions through two terms of lengthy experimentation were greatly appreciated.

Thanks are gratefully extended to the technicians and machinists of the Sloan Automotive Laboratory: Messrs. Paul Wassmouth and Herbert Johnston, who did all of the actual machining of test section parts and necessary insulators; Messrs. Joseph Caloggero, Larry Ristuccia and Edward Donahue, who offered advice and physical assistance in apparatus modifications and control; and Mr. J. C. Livengood, whose suggestions aided considerably at many critical points in the investigation. The assistance of Mrs. Mary Helen Wosser as part of the experimental team during actual operation of the apparatus is acknowledged with sincere appreciation.

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NOMENCLATURE

Symbol

L	Length of heated surface (hot spot)
M	Molecular weight
m	Number of moles
mv	Millivolt reading of potentiometer
p	Pressure in inches of mercury
R	Specific gas constant
T	Temperature in degrees Fahrenheit or Rankine
V	Velocity in ft per sec.
w	Mass flow rate in lbs per sec.
$(w_f/w_a)_s$	Stoichiometric fuel-air ratio
ΔP	Pressure difference in inches of water
ρ	Mixture density in lbs per cu ft.

Subscripts

a	Air
f	Fuel
n	Nozzle condition
o	Refers to free-stream condition
w	Refers to condition at hot spot surface or wall
wa	Apparent or observed condition
1	Inlet air condition

SURFACE IGNITION IN A STEADY-FLOW APPARATUS

INTRODUCTION

The effect of fuel-air ratio on conditions required for ignition of a homogeneous combustible mixture by means of a heated surface is investigated experimentally. This investigation is part of a program started recently at the Massachusetts Institute of Technology in which theoretical and experimental studies of the surface ignition problem are being conducted using the same model. In the past, researchers have conducted experiments using an igniter immersed in the mixture stream. Since ignition in these cases was initiated in the wake region near the trailing edge of the igniter, correlation of the results with theory was very difficult.

By making the heated surface a part of a cylindrical combustor wall, ignition initiated by the heated surface was analyzed theoretically by boundary-layer theory and experimentally in a steady-flow apparatus. Professor T. Y. Toong of the Massachusetts Institute of Technology has proposed the theory (Ref. 1). The theory assumes laminar flow of the mixture over an isothermal flat plate. The mixture is considered to be a perfect gas with constant properties, except that its viscosity and thermal conductivity vary directly with absolute

temperature. The chemical reaction proceeding in the boundary layer is assumed to be of the Arrhenius type of the second order. The theory indicates that for a mixture of given composition, other things being equal, incipient ignition occurs at the same flat plate temperature if the free stream velocity varies directly with the free stream density, the flat plate length, or their product. The validity of this part of the theory has been shown by the results obtained in four investigations - Davis (Ref. 2), Barkah (Ref. 3), Sellman and Snyder (Ref. 4), and Harper (Ref. 5) - over a limited range of the variables involved.

Experimental work was started by Davis (Ref. 2), who designed the basic apparatus used by the other investigators. Davis' design provided for heating a two-inch long, 60° sector of a cylindrical test section one-half inch in diameter. The sector was heated with an oxygen-acetylene torch, and the temperature measured with thermocouples. Ignition was detected by a spark-plug ionization gap. Davis operated the equipment and found that it should be satisfactory for obtaining the desired results. Preliminary tests did indicate that surface temperature for ignition varied with the free-stream velocity.

Barkah (Ref. 3) modified the apparatus by placing three quartz windows directly across the test section from the heated surface. This enabled the surface temperature to be measured

by an optical pyrometer. Barkah found that the surface temperature required for ignition varies inversely with free-stream temperature. A plot of surface temperature versus free-stream velocity showed a concave downward curve of positive slope.

Sellman and Snyder (Ref. 4) modified the apparatus by heating the entire surface of a two-inch-long cylindrical test section, one-half inch in diameter. The heating was accomplished by an induction heating coil surrounding the test section. Surface temperature inside the test section was measured by optical pyrometer observations on the outer surface of the test section since they reported a maximum of 8°F difference between the inner and outer wall temperatures. Sellman and Snyder's results show that substantially the same surface temperature is required for ignition if the free-stream velocity varies directly with free-stream density. The concave downward shape of the surface temperature versus velocity curve, as reported by Barkah, was verified.

Harper (Ref. 5) modified Davis' apparatus to accomodate a four-inch heated sector of the cylindrical test section. Four oxygen-acetylene torches were used to heat the sector and the surface temperature was measured with an optical pyrometer. A four-inch pyrex window was placed opposite the heated surface so that the temperature distribution along

the entire length of the surface could be measured. Harper found that by plotting surface temperature required for ignition versus the ratios of free-stream velocity to the product of free-stream density and heated surface length ($V/\rho_o L$), the results reported for the two-inch length agreed quite well with the four-inch results. The temperature required for ignition increases with increasing $V/\rho_o L$, the curve being concave downward. These findings also agree with the proposed theory.

A theoretical analysis of the effect of fuel-air ratio on the surface temperature required for ignition has not yet been made. However, the effect of this variable is of great interest and is investigated experimentally in this report. The apparatus of Harper is used with a few modifications.

APPARATUS

A schematic diagram of the apparatus is shown in Fig. 1. The basic design of Davis and the test section used by Harper were utilized except for modifications described in Appendix I.

General

Atmospheric air is supplied to the system by a vacuum pump capable of delivering 700 cu ft per min. A one-inch throttling valve controls the flow of inlet air. An ASME 0.230 inch square edged orifice meters the flow to the steam jacketed mixing tank. Steam pressure up to 70 psi is fed to the tank to heat the fuel-air mixture. Absolute pure ethyl alcohol is supplied by a gear pump driven by an electric motor. The fuel flow is metered to the mixing tank by a Fischer and Porter rotameter with a 06-150 tube and a 3/32 inch diameter glass ball float.

The heated mixture flows from the tank to a straightening section 1-1/2 inches in diameter. Inside the section is a bank of small tubes one-eighth inch in diameter and three inches long followed by four 100 mesh wire screens. A brass nozzle with a contraction ratio of nine introduces the flow to the test section. At the exit of the test section is a Vicor glass observation tube one-half inch in diameter and

approximately 30 inches long. From this tube the flow proceeds to a water-cooled exhaust tank and then to the laboratory exhaust system through a one-inch globe valve. Excess air is brought into the exhaust system from another test cell to reduce the hazards of a combustible mixture in laboratory lines.

Pressure taps are provided at each side of the air metering orifice, in the straightening section, and in the exhaust tank. Pressures are indicated on mercury and water manometers. A thermocouple, shielded from hot spot radiation, is placed in the free stream between the second and third screens. Another thermocouple is embedded in the nozzle wall. Both thermocouples are copper-constantin and their temperatures indicated on a Leeds and Northrup potentiometer. A mercury thermometer measures the inlet air temperature.

A CO_2 inlet is placed between the first and second screens to extinguish prolonged or uncontrolled burning. Cooling water for the fuel, nozzle, and exhaust tank is provided.

Test Section

An exploded view of the test section assembly is shown in Fig. 2. The housing and clamps are made of 303 stainless steel. The hot spot is made of Nichrome V, a trade name used by Driver-Harris Company, which contains 80 per cent nickel and 20 per cent chromium. The surface of the hot spot, which

covers 60° of the cylindrical test section, is heated from the rear by impinging the flames of four oxygen-acetylene torches into the cavity provided. The surface temperature of the hot spot is measured by a Leeds and Northrup optical pyrometer. Observation of the surface is made through the 5/32 inch thick pyrex window located on the opposite wall of the test section.

Insulation of test section components is accomplished with no. 90 Garlock rubberized asbestos. The detailed shapes of these insulators are shown in Fig. 3.

TEST PROCEDURE

The two principal variables for all runs are hot spot surface temperature, measured by the optical pyrometer, and fuel-air ratio, controlled by the air and fuel flow rates to the mixing tank. To determine the true effect of fuel-air ratio, an attempt is made to hold the following factors constant while varying the fuel-air ratio (see Appendix II):

(1) Free-stream velocity

(2) Free-stream density of the mixture

(3) Free-stream temperature

(4) Nozzle temperature

Prior to each day's running, the apparatus is warmed up by admitting high-pressure steam to the mixing tank and coils surrounding the straightening section. The steam pressure is adjusted to approximately 60 psi after the condensed liquid is purged from the tank. Next, the suction pump of the laboratory exhaust system is turned on, and the approximate test section flow rate for the coming runs established by adjusting the inlet air throttling valve and the exhaust-line valve of the apparatus.

The cold junctions for the nozzle and free-stream thermocouples are provided by a one-quart thermos bottle filled with ice and water. The junctions are immersed in the ice

bath in glass tubes running through the thermos cork. The potentiometer is connected to the thermocouple selector switch at the control panel.

The optical pyrometer is placed in position for viewing the hot spot surface through the pyrex window in the test section. In aligning the optical pyrometer, care is taken to insure that the line of sight from the pyrometer is perpendicular to the hot spot surface. This is important if readings are to be consistent with previous calibrations.

When the free-stream temperature reaches a value of 620°R the cooling water for the torches, nozzle, fuel, and exhaust tank spray nozzles are turned on. Next, the oxygen-acetylene torches are lighted and the flames at the four tips adjusted to heat the hot spot evenly to a temperature of about 1800°F. Steam pressure is adjusted to hold the free-stream temperature at 634°R. The nozzle cooling water flow is adjusted to maintain nozzle temperature at 634°R so that there will be no heat transfer between the mixture and the nozzle. This is important since the free-stream temperature used for mixture density calculations is measured upstream of the nozzle. When the hot spot temperature reaches 1800°F the asbestos insulators surrounding the test section affect a seal and a leak test is made. This is accomplished by closing the inlet air throttle valve and allowing the suction pump to create a vacuum in the apparatus. When pressure

in the section upstream of the nozzle (p_o) indicates -5.0 inches of mercury on the manometer board, the apparatus exhaust valve is quickly closed. The loss of vacuum from -5.0 inches of mercury gage to -1.0 inches of mercury gage with all valves closed is timed. A time of 60 seconds or greater is considered satisfactory. The inlet air throttle valve and exhaust valve are again adjusted to give the desired flow.

Next, the CO_2 tank is turned on and flow of CO_2 to the straightening section by operating the emergency extinguishing valve is checked for proper functioning. Then the fuel container is unsealed and connected to the fuel pump. The rotameter is set to give an approximate stoichiometric mixture flowing through the test section. The torches are turned up to give a hot spot temperature approximately 50°F below expected ignition temperature. When the hot spot temperature stabilizes, a temperature distribution over the length of the hot spot is taken by measuring the temperature every one-fourth to one-half inch. The individual torches are adjusted to obtain as even a temperature distribution as possible. An average is determined and the pyrometer set to read at a point on the hot spot that yields that average temperature.

The torches are now turned up to raise the hot spot temperature to approximately 20°F below the expected ignition point. Final adjustments to fuel flow and air flow are made

to give the desired velocity, density, and fuel-air ratio while maintaining free-stream and nozzle temperatures at 634°R. Approximately one minute is allowed for steady-state conditions to be reached. Then the torches are turned up slightly so that the hot spot temperature increases. The optical pyrometer is read continually as the temperature approaches the point of ignition. This ignition point is detected by (1) a sudden decrease in pressure difference across the air metering orifice, as indicated by the ΔP manometer, (2) flame visible in the Vicor tube downstream of the test section, (3) flashing over the hot spot visible through the optical pyrometer, and (4) sudden rise in hot spot temperature measurements.

At the time of ignition the following readings are taken and recorded:

(1) Pressure difference across air metering orifice, (ΔP), prior to ignition

(2) Free-stream pressure (p_o)

(3) Inlet-air pressure (p_1)

(4) Potentiometer reading for free-stream temperature (mv_o)

(5) Potentiometer reading for nozzle temperature (mv_n)

(6) Temperature of inlet air (T_1)

(7) Temperature of fuel (T_f)

(8) Rotameter reading (Roto)

(9) Apparent hot spot temperature (T_{wa})

As soon as ignition is detected the fuel flow is turned off at the rotameter to prevent prolonged burning and consequent damage to the apparatus. The torches are also turned down to reduce the hot spot temperature to about 20°F below the ignition point, and the apparatus is readied for another run.

Actual operation of the apparatus, including data recording, was found to require a minimum of three persons. For best results, four persons were used when they were available. Since the principal variable for the majority of the runs was fuel-air ratio, the exact maintenance of steady fuel and air flow were essential. One person maintained rotameter setting constant to give the desired fuel flow. Operation of the oxygen-acetylene torches and measurement of the hot spot temperature with the optical pyrometer occupied a second person's time. The third person was responsible for the control and measurement of all pressure and temperature variables. Maintenance of nozzle temperature at the desired value occupied a good part of the third operator's time.

It is felt that in the majority of the recorded runs, and most certainly after April 1, the accuracy of measurements and fineness of control were as good as could be achieved with this apparatus.

RESULTS AND DISCUSSION

The surface ignition problem in the steady-flow apparatus constructed at the Massachusetts Institute of Technology has several variables. Previous investigations have shown the effect on ignition temperature of varying free-stream velocity, density, and temperature of a stoichiometric ethanol-air mixture. The effect of heated surface length has also been shown. From these investigations a parameter $V/\rho_o L$ was found useful in correlating the results. Fig. 4 shows a curve compiling the results obtained thus far, as interpreted by Professor T. Y. Toong. Surface temperature required for ignition is seen to increase as $V/\rho_o L$ increases and the curve is concave downward.

In the present investigation it was decided to determine the effect of varying fuel-air ratio while holding $V/\rho_o L$ essentially constant. Although Davis (Ref. 2) reported difficulty in reproducing data in the fuel rich range, it was felt that this variable was important to the problem and an attempt should be made to investigate its effects.

A value of $V/\rho_o L$ equal to 1828 was chosen as the first point to investigate. This value represents a free-stream velocity of 35 ft per sec., a density of 0.0575 lb per cu ft., and a heated surface length of four inches. Physical intuition

indicates that at some fuel-air ratios a surface temperature greater than that shown in Fig. 4 will be required to ignite the mixture. Therefore, this relatively low $V/\rho_o L$ was chosen to keep surface temperatures as low as possible over a wide range of fuel-air ratios. Surface temperature was a limiting factor since Nichrome V scales at about 2200°F causing the surface to become rough and irregular.

The results obtained by varying fuel-air ratio while maintaining $V/\rho_o L$ approximately constant at 1828 are tabulated in Table I and plotted in Fig. 5. It is seen that the minimum surface temperature required for ignition remains essentially constant at 2425°R from 0.73 to 1.65 times the stoichiometric fuel-air ratio, $(w_f/w_a)_s$. At less than 0.73 $(w_f/w_a)_s$ the temperature required increases rapidly and for mixture ratios greater than 1.65 $(w_f/w_a)_s$ the increase is slower. A maximum of 2.60 $(w_f/w_a)_s$ could be attained with the rotameter used, when operating at $V/\rho_o L$ equal to 1828. Ability of the Nichrome V to withstand temperatures required for ignition was the factor limiting investigation in the low fuel-air ratio range.

Fig. 5 also shows that experimental scatter increases at the low and high, as compared to stoichiometric, fuel-air ratios. It is believed that this scatter is due to unpredictable air leaks in the test section. Such leaks change the fuel-air ratio and hence the ignition temperature. Some

tabulated results were not included in the graphical presentation if excessive leaks were found to exist during the runs. An attempt was made to reduce the scatter by frequently changing the test section insulators, and to some extent this was successful. Another factor that contributed to the scatter was instability of the flow in the region beyond 1.65 $(w_f/w_a)_s$. In this region it was noted that flow instability commences as surface temperature exceeds that required for ignition at stoichiometric fuel-air ratio. The flow became more unstable with increasing surface temperature until the ignition point was reached. These instabilities were indicated by fluctuations in the pressure manometers similar to those caused by the sudden back pressure when actual ignition occurs. It is possible that intermittent ignitions were occurring but not being sustained. However, the presence of even intermittent ignitions were not visually observed in the test section or the Vicor glass tube. None of these instabilities were noted in the fuel-lean range.

The effect of varying fuel-air ratio at a constant $V/\rho_o L$ of 2645 was similarly investigated. This condition represents a velocity of 50.7 ft per sec., a density of 0.0575 lb per cu ft., and a heated surface four inches long. The data obtained is recorded in Table II and plotted in Fig. 5. The curve is similar in shape to that obtained at the lower value of $V/\rho_o L$.

The minimum surface temperature required for ignition is essentially constant at 2470°R from 0.77 $(w_f/w_a)_s$ to 1.32 $(w_f/w_a)_s$. Again the temperature required rises sharply at low fuel-air ratios and more gently at high fuel-air ratios. Greater experimental scatter of data beyond 1.32 $(w_f/w_a)_s$ is also apparent, and flow instability was again observed in this fuel-rich region when operating above the minimum temperature required for ignition at stoichiometric fuel-air ratio. Flow instability was not observed in the region below 0.77 $(w_f/w_a)_s$, and scatter in this region is attributed to air leaks in the test section.

Experimental scatter over the constant temperature portions of both curves in Fig. 5 is less than 15°F.

In Ref. 6, the limits of inflammability determined at atmospheric pressure and room temperature for upward propagation in a tube two inches or more in diameter were given as 3.28 and 18.95, on a per-cent-by-volume basis. Conversion of these values to fuel-air ratios indicate the range of inflammability to be from 0.49 $(w_f/w_a)_s$ to 3.34 $(w_f/w_a)_s$. It is also interesting to note that the range of fuel-air ratios over which a constant surface temperature was required for ignition in this study became more narrow at the higher value of $V/\rho_o L$. Unfortunately, this investigation did not determine if this trend continued with increasing values of $V/\rho_o L$.

Some early runs in this study did indicate that the temperature required for ignition increased immediately when fuel-air ratio was varied from the stoichiometric value. It is felt that the authors lacked familiarity with the apparatus at that early stage and had not developed the technique required to maintain all variables at their desired values. For this reason the early results are not included in this presentation.

In comparing Figs. 4 and 5, it is seen that at both values of $V/\rho_o L$ chosen, the surface temperatures required for ignition at stoichiometric fuel-air ratios are lower in this investigation than those reported in previous studies. At $V/\rho_o L$ equal to 1828 the difference is 32°F and at 2645 the spread is 37°F. For all the data represented in these two figures the free stream temperature was maintained at 634°R. In the present investigation the nozzle temperature is also maintained at approximately 634°R for all runs. No attempt was made to control this variable in the other investigations, except that Sellman and Snyder (Ref. 4) did report that the nozzle temperature varied between 560°R and 585°R. It is believed that nozzle temperature is very important since the mixture flows through the nozzle after its free-stream temperature has been measured in the straightening section. With the nozzle temperature at 634°R, minimum heat

transfer between the mixture and nozzle should occur. The effect of a relatively cool nozzle (580°R) on the heated mixture (634°R) would undoubtedly be a decrease in temperature of the mixture entering the test section. According to the theory (Ref. 1) and experimental work by Barkah (Ref. 3), a decrease in free-stream temperature will require an increase in surface temperature to ignite the mixture. It is believed that this effect could account for the discrepancies in the ignition temperatures obtained.

Surface temperatures required for ignition at stoichiometric fuel-air ratios were checked at two higher values of $V/\rho_o L$, 3210 and 3820. The results are tabulated in Table III and plotted in Fig. 6 along with two points representing averages of many ignition temperatures at the stoichiometric point obtained at the two lower values of $V/\rho_o L$ (Tables I and II). The curve of Fig. 4 is replotted in Fig. 6 to show that over the range of $V/\rho_o L$ values checked, the curves are of similar shape but the ignition temperatures of this investigation are significantly lower than those previously reported. An attempt was made to obtain data at a $V/\rho_o L$ equal to 4580. However, this required a free stream gage pressure of about -12.0 inches of mercury which caused failure in the test section insulators.

To verify the effect of nozzle temperature on ignition temperature, runs were made at the four values of $V/\rho_o L$

already investigated but this time maintaining nozzle temperature at approximately 580°R. The results are tabulated in Table IV and the data plotted in Fig. 6. It is seen that these points fall within the experimental scatter range of the curve representing the results of the previous investigators. It is therefore concluded that the difference in the two curves of Fig. 6 is due to nozzle temperature.

The results of leak tests made during operating periods are shown in Figs. 7 and 8. The plots in each case show the time required for the closed system to lose vacuum from -5.0 inches of mercury gage to -1.0 inch of mercury gage. A time of 60 seconds or greater was considered to be acceptable. Leaks around the test section increased rapidly when operating at high temperatures, which necessitated changing insulators around the hot spot frequently.

Figs. 9 and 10 show temperature distributions along the heated surface length during operating periods. In each case a mean line through the distribution was determined, and a point on the surface was chosen to yield the mean-line temperature when measured with the optical pyrometer. Although the heated surface effective length was probably less, the actual length of four inches was used in all computations.

Sample calculations used in determining the desired operating conditions are shown in Appendix III.

CONCLUSIONS AND RECOMMENDATIONS

1. At a value of $V/\rho_o L$ equal to 1828 the minimum temperature required for ignition remains essentially constant at 2425°R from 0.73 to 1.65 times the stoichiometric fuel-air ratio. At less than 0.73 $(w_f/w_a)_s$ the temperature required increases rapidly and for mixtures greater than 1.65 $(w_f/w_a)_s$ the increase is slower.

2. At a value of $V/\rho_o L$ equal to 2645 the minimum temperature required for ignition remains constant at 2470°R from 0.77 $(w_f/w_a)_s$ to 1.32 $(w_f/w_a)_s$. At less than 0.77 $(w_f/w_a)_s$ the temperature required rises sharply and at greater than 1.32 $(w_f/w_a)_s$ the rise is more gradual.

3. At both values of $V/\rho_o L$ experimental scatter increased in the fuel-rich region where the slope of the curve became positive. In this same region the flow became very unstable, with possible intermittent ignitions, when operating above the minimum temperature required for ignition at stoichiometric fuel-air ratio. The experimental scatter is attributed to unpredictable air leaks in the test section and flow instability.

4. At both values of $V/\rho_o L$ experimental scatter increased in the fuel-~~rich~~ lean region where the temperature required for ignition is rising rapidly. No evidence of flow instability in this region was observed. Experimental scatter is attributed

to unpredictable air leaks in the test section.

5. The range of fuel-air ratios over which constant surface temperature is required for ignition is more narrow at the high value of $V/\rho_o L$. Future studies should determine if this trend continues as $V/\rho_o L$ increases.

6. The plot of surface temperature required for ignition versus $V/\rho_o L$ is a concave downward curve of positive slope. It is similar in shape to a plot of previous results but ignition temperatures of this study occur from 32°F to 43°F lower over the range of $V/\rho_o L$ values investigated.

7. It was found that by maintaining nozzle temperature below 580°R, as previous investigators had done, it was possible to reproduce their results. It was therefore concluded that the higher ignition temperatures previously obtained were due to low values of nozzle temperature.

8. It is felt that further investigation with the present apparatus should not be attempted. A basic design change is needed to eliminate or reduce air leaks around the test section. This would be particularly important in any future study of fuel-air ratio effects.

APPENDIX I

APPARATUS MODIFICATIONS AND EFFECTS:

Apparatus modifications fall into two categories--those which reduce apparatus leaks and those designed to improve control of auxiliary systems. A very high percentage of laboratory time was spent in trying to reduce leaks, and many modifications short of complete redesign were attempted. Time was not available for a redesign of the apparatus and yet improving the accuracy of the results required better equipment. Therefore, it is felt that the modifications described below were well worth the time and effort expended.

The only major modification in the attempt to reduce leaks was the welding of a 1/8 inch 303 stainless steel washer to the upstream end of the test section, thereby sealing this end completely and eliminating the need for Harper's "C" clamp (Ref. 5) to maintain the geometrical shape of the test section at high hot spot temperatures. In addition this slight change in the test section completely eliminated all window leaks and made insulation of the nozzle from the hot spot more effective. In place of the U-shaped window clamp used by Harper, an elongated O-shaped clamp (Fig. 2) was substituted with attendant rubberized asbestos insulators (Fig. 3)

on each side of the window. This affected an air-tight seal through several weeks of operation.

The closing of the upstream end of the test section left an oblong cavity in which to put the hot spot and necessary insulators (Fig. 2). The insulators between the hot spot and test section are shown in Fig. 3. Harper used some hot spot insulators made of Lava A and some of rubberized asbestos. The plasticity of the rubberized asbestos aided in preventing leaks around the expanding hot spot as its temperature was increased; and for this reason the use of this material on all four sides of the hot spot was decided upon. When heated to about 1700°F the expansion of the hot spot is sufficient to completely seal all leaks around it. However, prolonged operation at high temperatures will burn out the rubberizing ingredient in the insulators and destroy their plasticity and sealing qualities. The insulators at the ends of the hot spot suffered in this respect most, and it was therefore necessary to make them accessible for changing without dismantling the entire test section. This was accomplished by extending the side insulators over the full length of the hot spot cavity and notching the end insulators to complete an effective hot spot insulation (Figs. 2 and 3). Another effect of this change was that a pressure leak test was no longer possible since it

was likely that the new end insulator would be blown out of position. Therefore a vacuum leak test replacing Harper's pressure test was developed. It was found experimentally that the closed system losing vacuum from -5.0 inches to -1.0 inch of mercury gage in 60 seconds was approximately equivalent to a pressure drop from +10.0 inches to +1.0 inch of mercury gage in 50 seconds.

The Lava washer separating the nozzle from the test section produced leaks due to its smooth faces. A paper asbestos washer, as shown in Fig. 3, was placed on each side of the Lava washer to reduce leaks and at the same time maintain insulation at this point. The Lava washer was eventually replaced by asbestos which made the seal at this point even more effective.

Because it was suspected that most of the remaining leaks were occurring around the glass observation tube, the cavity at the test section exit was countersunk an additional 0.030 inch to afford a better fit for the tube and its insulators. The tube connection at its downstream end was sealed by calking around it with asbestos rope material.

It was found necessary to modify the free-stream thermocouple shield to insure that it remained co-axial with the straightening section. The screens downstream of the thermocouple were removed so that the shield could be observed

through the nozzle. As air flowed through the straightening section, the shield turned crossways and tended to slip off the thermocouple. To correct this condition, the downstream end of the shield was lengthened so that it protruded through the third screen approximately one-eighth inch. With the shield held firmly in position, the thermocouple measures free-stream temperature with a minimum of hot spot radiation effects.

The one-inch inlet air globe valve was replaced by a one-half inch globe valve with a throttling nut to improve the control of air flow.

APPENDIX II

CONTROL AND MEASUREMENT:

a) Air Flow:

Air from the atmosphere is supplied to the system by the exhaust vacuum pump. An ASME square edged orifice of 0.230 inch diameter in a two-inch pipe is used to meter the flow on its way to the mixing tank. Prior to the period during which all the usable data was taken the orifice plate was removed from the inlet pipe and very carefully cleaned. The flow rate (w_a) is determined by use of the orifice equation for the 0.230 plate used (Ref. 7). Fig. 11 is a plot of standard air flow rate versus pressure difference (ΔP) across the orifice. The inlet air temperature (T_1) and pressure (p_1) are measured just ahead of the metering orifice, and on the basis of these two readings the flow rate obtained from Fig. 11 is corrected for the non-standard air density condition.

The air flow rate is controlled by the throttling valve at the atmospheric inlet and the globe valve in the laboratory exhaust system line. These same two valves also control the free-stream pressure (p_o) in the straightening section, which with free-stream temperature (T_o) measured in the straightening section controls the mixture density entering the test section.

All pressures are indicated on standard manometers, the ΔP across the metering orifice measured in inches of water, and p_o and p_1 in inches of mercury. The ΔP is read to the nearest 0.05 inches of water, p_o to the nearest 0.02 inches of mercury, and p_1 only to the nearest 0.05 inches of mercury. Inlet air temperature (T_1) and free-stream temperature (T_o) are both read to the nearest whole degree Fahrenheit.

b) Fuel Flow:

Absolute pure ethyl alcohol in a five-gallon container, kept sealed until ready for use, is supplied to the rotameter by a gear pump driven by an electric motor. The rotameter is used to deliver the desired fuel flow to the mixing tank.

Vent air to the fuel container passes through a metal housing containing activated alumina crystals for the removal of moisture. This is necessary because of the hygroscopic qualities of absolute pure ethyl alcohol. A pressure regulator maintains a constant fuel pressure of 24 psig. Fuel temperature at the pump is controlled by cooling water and held at approximately 70°F.

The rotameter was calibrated by disconnecting the fuel line to the mixing tank and leading it to a laboratory liquid flow calibrating apparatus, which consisted of a balance and an electric timer. The balance weighed the amount of fuel in measured time intervals, at different rotameter settings. The fuel temperature was held constant at 70°F during the calibration. The results are shown in Fig. 12.

The fuel flow rate is measured to the nearest 0.5 division on the rotameter scale.

c) Hot Spot Temperature:

The surface of the hot spot is heated by the oxygen-acetylene torches. It was found that by exercising extreme care the temperature distribution over the center 3-1/2 inches of the surface could be controlled to within 50°F. No variation in the lateral temperature distribution can be measured.

The hot spot apparent temperature (T_{wa}) was measured with an optical pyrometer (Ref. 8). The optical pyrometer compares the brightness of a lamp filament with that of the surface being observed. After the filament brightness is adjusted to match the surface, the radiation of the filament is indicated by reading the pyrometer lamp current. The pyrometer indicator is actually calibrated to read the lamp current in temperature of a black body emitting the same amount of radiation as the lamp filament. Since most objects are not true black bodies, the temperature indicated by the pyrometer will be lower than the actual temperature of the object. The necessary temperature correction depends on the emissivity of the material. Roeser (Ref. 9) found that the emissivity of a metal with the same composition as Nichrome V varied from 0.89 to 0.90 over the range of temperatures used in this investigation. Ref. 9 contains a tabulation of apparent and true surface temperatures for this material. A plot of that data is shown in Fig. 13.

The optical pyrometer used was checked with a second pyrometer calibrated at the U. S. Bureau of Standards. The check was made by sighting both pyrometers on the same section of a tungsten filament and taking consecutive readings throughout the range of expected use. The temperature of the tungsten filament was controlled by a variac and raised in small increments from 1800°F to 2300°F. At no point in over 30 settings did the readings of the two vary more than 3°F, and therefore no calibration correction was made.

To determine the transmittance of the 5/32 inch pyrex window, pyrometer readings of the filament temperature were taken as seen through the window while it was installed in the test section housing. These readings were checked by simultaneous observations of the filament with the standard pyrometer and no pyrex window. Sighting through the pyrex lowered the measured temperature by about 28°F throughout the range of 1900°F to 2250°F. An exact plot of these results is shown in Fig. 14.

Fig. 15 combines the corrections of Fig. 13 for emissivity and Fig. 14 for transmittance to give true hot spot temperature (T_w) versus apparent hot spot temperature (T_{wa}).

d) Free Stream Temperature:

Free-stream temperature is controlled by adjusting the steam pressure in the jacketed mixing tank and heating coils surrounding the straightening section. A maximum steam pressure

of about 70 psi can be attained. This is sufficient at all operating velocities to maintain a free-stream temperature of 634°R. When the stream temperature becomes too high, quick cooling of the mixing tank is accomplished by admitting cold water at the top.

The free-stream temperature is measured by a copper-constantin thermocouple located on the longitudinal axis of the straightening section. The thermocouple is shielded from possible hot spot radiation. A cold junction reference is supplied by an ice and water bath. The temperature is obtained by reading the thermocouple voltage on the potentiometer. Temperatures to the nearest degree Fahrenheit are recorded.

The thermocouple was checked by placing it in boiling water and obtaining the calibration temperature indicated by the potentiometer voltage.

e) Nozzle temperature:

Nozzle temperature is controlled by the flow of cooling water to the nozzle. Nozzle temperature is easily maintained at any temperature between 570°R and 660°R.

The temperature is measured by a copper-constantin thermocouple embedded in the nozzle wall. The method of reading temperatures and calibrating the thermocouple are the same as covered above for free-stream temperature.

Temperatures to the nearest degree Fahrenheit are recorded.

APPENDIX III

SAMPLE CALCULATIONS:

Establishing desired operating conditions:

Given:

Stoichiometric fuel-air ratio = 0.111

Molecular weight of Ethyl Alcohol (M_f) = 46

Molecular weight of air (M_a) = 29

Desired conditions:

ρ_o = 0.0575 lbs per cu ft.

V = 35.0 ft per sec.

T_o = 634°R

w_f/w_a = 1.4 stoichiometric fuel-air ratio

Mixture gas constant:

Weight of air to burn one mole of fuel at stoichiometric fuel-air ratio:

$$w_a = \frac{w_f}{0.111}$$

$$w_a = \frac{46}{0.111} = 414$$

Number of moles of air to burn one mole of fuel at stoichiometric fuel-air ratio:

$$m_a = \frac{w_a}{M_a}$$

$$m_a = \frac{414}{29} = 14.3 \text{ moles}$$

Molecular weight of mixture at 1.4 stoichiometric fuel-air ratio:

$$M = \frac{1.4\ (M_f) + 14.3\ (M_a)}{15.7}$$

$$M = \frac{1.4\ (46) + 14.3\ (29)}{15.7} = 30.5$$

Mixture gas constant:

$$R = \frac{1545}{M} = \frac{1545}{30.5} = 50.6 \text{ (see Fig. 16)}$$

Free stream pressure:

$$p_o = \rho_o R T_o \left(\frac{29.92}{2116}\right)$$

$$p_o = (0.0575)\ (50.6)\ (634)\ \left(\frac{29.92}{2116}\right) = 26.1 \text{ in Hg.}$$

Mixture flow rate:

$$w = \rho_o A V$$

$$w = (0.0575)\ \left(\frac{\pi}{4}\right)\ \left(\frac{1}{2}\right)^2\ \left(\frac{1}{12}\right)^2\ (35) = 0.002745 \text{ lbs per sec.}$$

Air flow rate:

$$w = w_f + w_a$$

since $w_f/w_a = 1.4\ (0.111)$

$$w = 1.4\ (0.111) w_a + w_a$$

$$w = 1.155\ w_a$$

$$w_a = \frac{0.002745}{1.155} = 0.002376 \text{ lbs per sec.}$$

Enter the air orifice calibration curve (Fig. 11) and read approximate ΔP. Adjust the flow in the apparatus to obtain the desired p_o and approximate ΔP. Read p_1 and T_1 to correct the orifice calibration for non-standard density. A corrected ΔP is obtained from the orifice curve by entering with:

$$w_{a_{chart}} = \frac{w_a}{\sqrt{\frac{p_1}{29.92} \times \frac{520}{T_1}}}$$

Re-adjust the flow to obtain a new ΔP and check p_1. If there is any change, repeat the procedure. One iteration is usually sufficient.

Fuel flow rate:

$$w_f = (1.4)\ (0.111) w_a$$

$$w_f = (1.4)\ (0.111)\ (0.002376) = 0.000369 \text{ lbs per sec.}$$

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TABLE I

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
3-14	1	104	30.28	-3.80	-3.00	8.90	178	-	77	68	9.25	2.75	2.470	2.745	0.111	0.0572	35.2	1845	1964	2467	1.00	no	Reading hottest spot
"	2	-	"	-3.75	-3.00	8.90	178	-	77	68	9.25	2.75	2.470	2.745	0.111	0.0572	35.2	1845	1976	2473	1.00	"	
"	3	-	"	-3.75	-2.90	8.80	178	-	77	69	9.40	2.81	2.450	2.731	0.115	0.0572	35.0	1835	1998	2502	1.04	"	
"	4	-	"	-3.75	-2.90	8.80	177	-	77	70	9.40	2.81	2.450	2.731	0.115	0.0573	34.9	1827	2000	2504	1.04	"	
"	5	-	"	-3.76	-2.90	8.75	174	-	77	71	9.50	2.88	2.446	2.734	0.118	0.0576	34.8	1812	2041	2546	1.06	"	
"	6	-	"	-3.79	-2.90	8.75	174	-	77	69	9.50	2.88	2.446	2.734	0.118	0.0575	34.8	1815	2040	2545	1.06	"	
"	7	-	"	-3.75	-2.90	8.65	176	-	77	70	9.70	3.02	2.342	2.734	0.124	0.0575	34.8	1815	2050	2555	1.12	"	
"	8	-	"	-3.80	-2.90	8.70	178	-	77	69	9.70	3.02	2.441	2.743	0.124	0.0573	35.1	1837	2051	2556	1.12	"	
"	9	-	"	-3.79	-2.90	8.55	178	-	77	70	9.95	3.15	2.420	2.735	0.130	0.0575	34.9	1820	2059	2565	1.17	"	Green flame
"	10	-	"	-3.78	-2.90	8.55	178	-	77	70	9.95	3.15	2.420	2.735	0.130	0.0575	34.9	1820	2059	2565	1.17	"	
"	11	-	"	-3.80	-2.90	8.40	174	-	77	68	10.15	3.29	2.400	2.729	0.137	0.0580	34.5	1785	2068	2575	1.23	"	
"	12	-	"	-3.78	-2.90	8.40	176	-	77	70	10.15	3.29	2.400	2.729	0.137	0.0578	34.6	1795	2068	2575	1.23	"	
"	13	-	"	-3.78	-3.00	8.85	172	-	77	68	9.25	2.75	2.470	2.745	0.111	0.0578	34.8	1805	1970	2473	1.00	"	Insulator broken
3-22	1	92	29.72	-3.22	-2.35	8.85	176	224	78	67	9.25	2.75	2.470	2.745	0.111	0.0573	35.1	1837	1965	2468	1.00	no	
"	2	-	"																				Flashback into straightening section
3-28	1	98	30.13	-3.66	-2.65	8.85	175	186	79	70	9.25	2.75	2.460	2.735	0.112	0.0575	34.9	1820	1933	2436	1.01	no	Holding T_n equal 634 R
"	2	-	"	-3.63	-2.65	8.85	175	184	79	70	9.25	2.75	2.460	2.735	0.112	0.0575	34.9	1820	1936	2438	1.01	"	From here on - using 3
"	3	-	"	-3.65	-2.65	8.80	174	185	79	76	9.40	2.81	2.450	2.731	0.115	0.0576	34.7	1808	1945	2448	1.04	"	people to operate the
"	4	-	"	-3.63	-2.65	8.80	174	188	79	66	9.40	2.81	2.450	2.731	0.115	0.0576	34.7	1808	1943	2446	1.04	"	apparatus.
"	5	-	"	-3.69	-2.75	8.75	174	192	79	69	9.50	2.88	2.446	2.734	0.118	0.0576	34.8	1812	1950	2453	1.06	"	
"	6	-	"	-3.68	-2.75	8.75	174	186	79	70	9.50	2.88	2.446	2.734	0.118	0.0575	34.8	1815	1930	2433	1.06	"	Insulator in flow
4-1	1	128	30.26	-3.78	-2.78	8.85	174	174	79	68	9.25	2.75	2.460	2.735	0.112	0.0576	34.8	1812	1919	2422	1.01	yes	Reading average from
"	2	-	"	-3.75	-2.85	8.90	175	174	79	71	9.25	2.75	2.471	2.746	0.113	0.0576	34.9	1818	1919	2422	1.02	"	Temperature Profile
"	3	-	"	-3.76	-2.85	8.80	174	178	80	68	9.40	2.81	2.450	2.731	0.115	0.0576	34.7	1808	1920	2423	1.04	"	
"	4	-	"	-3.78	-2.85	8.80	174	182	80	70	9.40	2.81	2.450	2.731	0.115	0.0576	34.7	1808	1920	2423	1.04	"	
4-3	1	98	30.19	-3.70	-2.80	8.85	180	174	79	62	9.25	2.75	2.460	2.735	0.111	0.0571	35.0	1839	1949	2452	1.00	no	New can fuel
"	2	-	"	-3.69	-2.80	8.85	178	174	79	72	9.25	2.75	2.460	2.735	0.111	0.0572	35.0	1835	1955	2458	1.00	"	
"	3	-	"	-3.71	-2.80	8.80	174	174	79	70	9.40	2.81	2.450	2.731	0.115	0.0575	34.8	1815	1974	2477	1.04	"	
"	4	-	"	-3.76	-2.85	8.75	174	172	79	68	9.50	2.88	2.446	2.734	0.118	0.0576	34.8	1812	1987	2491	1.06	"	
"	5	-	"	-3.80	-2.90	8.65	176	172	79	70	9.70	3.02	2.433	2.735	0.124	0.0573	35.0	1831	1972	2475	1.12	"	
4-4	1	104	30.43	-3.96	-3.00	8.85	176	174	79	69	9.25	2.75	2.459	2.734	0.112	0.0574	34.9	1824	1937	2440	1.01	no	New hot spot - 4 people
"	2	-	"	-4.03	-3.20	8.65	176	174	79	69	9.70	3.02	2.420	2.722	0.125	0.0572	34.9	1830	1937	2440	1.13	"	now operating apparatus
"	3	-	"	-4.03	-3.20	8.65	174	174	79	70	9.70	3.02	2.420	2.722	0.125	0.0575	34.7	1810	1938	2441	1.13	"	

TABLE I (cont)

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-4	4	-	30.43	-4.10	-3.30	8.55	174	174	79	70	9.95	3.15	2.409	2.724	0.131	0.0575	34.7	1810	1925	2428	1.18	no	Poor Temperature Profile
"	5	-	"	-3.95	-3.10	8.85	174	174	79	70	9.25	2.75	2.452	2.727	0.112	0.0576	34.7	1808	1935	2438	1.01	"	
"	6	-	"	-3.98	-3.20	8.75	174	174	79	70	9.50	2.88	2.432	2.720	0.118	0.0576	34.6	1802	1955	2458	1.06	"	
"	7	-	"	-4.03	-3.20	8.65	174	174	80	71	9.70	3.02	2.420	2.722	0.125	0.0575	34.7	1810	1930	2433	1.13	"	
"	8	-	"	-4.13	-3.30	8.40	174	174	80	72	10.15	3.29	2.387	2.716	0.138	0.0576	34.5	1797	1920	2423	1.24	"	
"	9	-	"	-3.93	-3.00	8.85	174	174	80	69	9.25	2.75	2.459	2.734	0.112	0.0576	34.8	1812	1938	2441	1.01	"	
"	10	-	"	-4.23	-3.40	8.25	174	174	80	69	10.60	3.57	2.365	2.722	0.151	0.0576	34.6	1802	1924	2427	1.36	"	
"	11	-	"	-4.23	-3.40	8.25	174	174	80	69	10.60	3.57	2.365	2.722	0.151	0.0576	34.6	1802	1953	2456	1.36	"	
4-5	1	174	30.28	-3.78	-2.90	8.85	176	174	80	70	9.25	2.75	2.452	2.727	0.112	0.0574	34.8	1819	1926	2429	1.01	yes	Using asbestos paper
"	2	-	"	-3.88	-3.00	8.65	176	174	80	70	9.70	3.02	2.420	2.722	0.125	0.0572	34.9	1830	1926	2429	1.13	"	cut-outs top and bot-
"	3	-	"	-3.98	-3.00	8.40	180	174	80	69	10.15	3.29	2.387	2.716	0.138	0.0571	34.8	1812	1926	2429	1.24	"	tom of lava insulator
"	4	-	"	-4.08	-3.30	8.25	180	174	80	68	10.60	3.57	2.359	2.716	0.152	0.0570	34.9	1838	1926	2429	1.37	"	
"	5	-	"	-4.18	-3.40	8.05	174	174	80	67	11.10	3.84	2.329	2.713	0.165	0.0575	34.6	1804	1925	2428	1.49	"	
"	6	-	"	-4.28	-3.50	7.80	174	174	80	71	11.55	4.12	2.293	2.705	0.180	0.0576	34.4	1791	1926	2429	1.62	"	
"	7	75	"	-3.83	-2.90	8.75	168	174	80	74	9.50	2.88	2.440	2.728	0.118	0.0580	34.5	1785	1921	2423	1.06	"	
"	8	-	"	-3.78	-2.90	8.85	174	174	80	68	9.25	2.75	2.452	2.727	0.112	0.0576	34.7	1808	1925	2428	1.01	"	
"	9	-	"	-3.78	-2.90	8.85	179	182	80	63	9.25	2.75	2.452	2.727	0.112	0.0571	35.0	1839	1924	2427	1.01	"	
"	10	-	"	-3.88	-3.00	8.65	179	182	80	67	9.70	3.02	2.420	2.722	0.125	0.0571	34.9	1834	1924	2427	1.13	"	
"	11	196	30.15	-3.65	-2.90	8.85	178	166	80	73	9.25	2.75	2.447	2.722	0.112	0.0572	34.9	1830	1926	2429	1.01	"	
"	12	-	"	-3.75	-3.00	8.65	178	174	80	67	9.70	3.02	2.420	2.722	0.125	0.0571	34.9	1834	1929	2432	1.13	"	
"	13	-	"	-3.85	-3.10	8.40	174	174	80	70	10.15	2.29	2.384	2.713	0.138	0.0576	34.5	1796	1914	2417	1.24	"	
"	14	-	"	-3.95	-3.20	8.25	174	174	80	70	10.60	3.57	2.365	2.722	0.151	0.0575	34.7	1810	1913	2416	1.36	"	
"	15	-	"	-3.55	-2.80	9.15	174	174	80	70	8.80	2.47	2.495	2.742	0.099	0.0575	34.9	1820	1918	2421	0.89	"	Flame difficult to see
"	16	-	"	-3.45	-2.60	9.35	174	174	81	75	8.35	2.20	2.531	2.751	0.087	0.0575	35.0	1825	1912	2415	0.78	no	on lean runs
"	17	-	"	-3.35	-2.50	9.55	174	174	81	69	7.85	1.92	2.558	2.750	0.075	0.0575	35.0	1825	1912	2418	0.68	"	
"	18	42	"	-4.45	-3.75	7.25	174	174	81	68	13.00	4.95	2.200	2.695	0.225	0.0576	34.3	1786	1928	2431	2.03	"	Insulator in flow
"	19	86	"	-3.65	-2.90	8.85	174	174	81	69	9.25	2.75	2.455	2.730	0.112	0.0575	34.8	1815	1918	2421	1.01	yes	New insulators
"	20	-	"	-3.65	-2.90	8.85	174	174	81	69	9.25	2.75	2.455	2.730	0.112	0.0575	34.8	1815	1922	2425	1.01	"	
4-10	1	148	29.75	-3.29	-2.40	8.95	176	174	80	70	9.25	2.75	2.468	2.743	0.111	0.0573	35.1	1837	1922	2425	1.00	yes	New stainless steel
"	2	-	"	-3.35	-2.45	8.90	176	174	80	71	9.50	2.88	2.458	2.746	0.117	0.0573	35.1	1838	1923	2426	1.05	"	screens
"	3	-	"	-3.51	-2.65	8.60	173	174	81	66	10.15	3.29	2.419	2.748	0.136	0.0573	35.2	1842	1921	2424	1.22	"	
"	4	-	"	-4.01	-3.30	7.80	173	174	81	65	12.50	4.67	2.278	2.745	0.205	0.0576	34.9	1818	1926	2429	1.84	no	Ignition not sustained
"	6	-	"	-4.52	-3.80	7.00	174	174	81	70	14.90	6.04	2.146	2.750	0.281	0.0574	35.1	1833	-	-	2.53	"	No ignition - 2080 F
"	5	-	"	-4.32	-3.60	7.30	174	174	81	70	13.90	5.49	2.195	2.744	0.250	0.0575	35.0	1827	2001	2505	2.25	yes	Unstable before ignition
"	7	130	"	-3.29	-2.40	8.95	174	174	81	74	9.25	2.75	2.466	2.741	0.112	0.0575	35.0	1823	1922	2425	1.01	"	New insulators

TABLE I (cont)

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-10	8	-	29.76	-4.21	-3.50	7.50	175	186	81	78	13.45	5.22	2.226	2.748	0.233	0.0573	35.2	1842	1976	2479	2.10	yes	For all rich runs
"	9	67	"	-4.11	-3.30	7.60	174	168	92	69	13.00	4.95	2.248	2.743	0.220	0.0575	35.0	1827	1956	2459	1.98	"	flow unsteady
"	10	104	"	-4.01	-3.30	7.80	174	174	82	69	12.50	4.67	2.274	2.741	0.205	0.0575	35.0	1823	1964	2467	1.84	no	New insulators
"	11	-	"	-3.92	-3.20	8.00	174	174	83	70	12.00	4.40	2.323	2.763	0.189	0.0575	35.2	1840	1965	2468	1.70	"	
"	12	-	"	-3.29	-2.40	8.95	174	174	83	73	9.25	2.75	2.461	2.746	0.112	0.0575	35.0	1827	1934	2457	1.01	"	
"	13	85	"	-3.92	-3.20	8.00	174	174	83	73	12.00	4.40	2.323	2.763	0.189	0.0575	35.2	1840	1973	2481	1.70	"	Insulator in flow
4-11	1	189	30.03	-3.56	-2.70	8.95	176	174	80	70	9.25	2.75	2.465	2.740	0.112	0.0572	35.1	1840	1925	2428	1.01	yes	
"	2	-	"	-3.75	-2.90	8.70	176	174	80	70	9.95	3.15	2.426	2.741	0.130	0.0570	35.3	1858	1924	2426	1.17	"	
"	3	-	"	-3.98	-3.10	8.30	174	174	80	70	11.10	3.84	2.372	2.756	0.162	0.0575	35.1	1831	1929	2432	1.46	"	
"	4	50	"	-4.08	-3.20	8.10	172	174	80	70	11.55	4.12	2.336	2.748	0.176	0.0576	34.9	1820	1933	2436	1.58	no	New insulators
"	5	101	"	-4.20	-3.40	8.00	176	174	81	73	12.00	4.40	2.307	2.747	0.191	0.0573	35.2	1840	1952	2455	1.72	"	
"	6	-	"	-4.29	-3.50	7.80	176	177	81	68	12.50	4.67	2.282	2.749	0.205	0.0572	35.2	1845	1980	2484	1.84	"	
"	7	-	"	-4.38	-3.60	7.60	174	174	81	68	13.00	5.22	2.250	2.772	0.232	0.0577	35.2	1828	1955	2458	2.09	"	Insulator in flow
"	8	133	29.98	-3.51	-2.65	8.95	174	174	80	68	9.25	2.75	2.470	2.745	0.111	0.0576	34.9	1818	1925	2428	1.00	yes	New insulators
"	9	-	"	-3.50	-2.65	8.95	176	172	80	68	9.25	2.75	2.470	2.745	0.111	0.0573	35.1	1837	1925	2428	1.00	"	
"	10	-	"	-4.23	-3.45	7.80	174	172	80	69	12.50	4.67	2.282	2.749	0.204	0.0575	35.0	1827	1958	2461	1.84	"	
"	11	-	"	-4.14	-3.40	8.05	174	174	80	69	12.00	4.40	2.314	2.754	0.190	0.0575	35.1	1829	1926	2429	1.71	"	
"	12	-	"	-4.23	-3.45	7.80	174	174	81	70	12.50	4.67	2.282	2.749	0.204	0.0575	35.0	1827	1955	2458	1.84	"	
"	13	57	"	-4.14	-3.35	8.00	174	174	81	70	12.00	4.40	2.310	2.750	0.190	0.0575	35.0	1828	1928	2431	1.71	"	
"	14	96	29.94	-3.47	-2.60	8.95	184	184	81	66	9.25	2.75	2.470	2.745	0.111	0.0567	35.5	1875	1926	2429	1.00	"	
4-12	1	138	29.88	-3.40	-2.50	8.95	176	174	79	68	9.25	2.75	2.474	2.749	0.111	0.0572	35.2	1845	1929	2432	1.00	yes	
"	2	-	"	-3.93	-3.10	8.10	181	174	79	67	11.55	4.12	2.335	2.747	0.176	0.0569	35.4	1863	1930	2433	1.58	"	
"	3	-	"	-4.04	-3.30	8.00	179	178	79	70	12.00	4.40	2.308	2.748	0.191	0.0570	35.4	1861	1930	2433	1.72	"	
"	4	-	"	-4.13	-3.50	7.80	177	170	79	70	12.50	4.67	2.280	2.747	0.205	0.0572	35.2	1843	1942	2445	1.85	"	
"	5	-	"	-4.53	-3.80	7.15	176	177	79	70	14.40	5.76	2.179	2.755	0.265	0.0573	35.3	1845	2047	2554	2.39	"	
"	6	-	"	-3.41	-2.50	8.95	174	174	79	70	9.25	2.75	2.470	2.745	0.111	0.0575	35.0	1827	1924	2426	1.00	"	
"	7	49	29.85	-3.38	-2.50	8.95	174	186	80	74	9.25	2.75	2.470	2.745	0.111	0.0575	35.0	1827	1925	2428	1.00	"	
"	8	108	29.79	-3.30	-2.45	9.00	174	174	81	67	9.25	2.75	2.484	2.759	0.111	0.0575	35.1	1833	1922	2424	1.00	"	New insulators
"	9	-	"	-2.98	-2.10	9.40	174	175	81	70	7.85	1.92	2.540	2.732	0.076	0.0575	34.8	1816	2029	2534	0.69	"	
"	10	-	"	-3.10	-2.20	9.30	174	175	81	71	8.40	2.20	2.525	2.745	0.087	0.0575	35.0	1827	1925	2428	0.78	"	
"	11	-	"	-3.04	-2.15	9.40	174	174	81	73	8.10	2.06	2.538	2.744	0.081	0.0575	35.0	1826	1925	2428	0.73	"	
"	12	-	"	-2.97	-2.05	9.45	174	174	81	6[illegible]	7.85	1.92	2.551	2.743	0.075	0.0575	35.0	1825	1942	2445	0.67	"	
"	13	-	"	-3.22	-2.30	9.10	174	174	81	69	8.80	2.47	2.498	2.745	0.099	0.0574	35.0	1828	1924	2426	0.89	"	New insulators
"	14	-	"	-2.97	-2.10	9.45	174	174	82	70	7.85	1.92	2.544	2.736	0.076	0.0575	34.8	1818	1945	2448	0.69	"	
"	15	47	"	-2.93	-2.00	9.55	174	174	82	70	7.55	1.78	2.572	2.750	0.069	0.0575	35.0	1829	2062	2567	0.62	"	
"	16	98	29.76	-3.29	-2.45	8.95	174	174	83	82	9.25	2.75	2.465	2.740	0.112	0.0575	34.9	1820	1926	2429	1.01	"	

TABLE I (cont)

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-15	1	94	30.28	-3.81	-2.90	8.95	175	174	79	65	9.25	2.75	2.472	2.747	0.111	0.0574	35.1	1836	1921	2423	1.00	yes	Started using asbes-
"	2	-	"	-3.46	-2.60	8.50	175	174	79	69	7.85	1.92	2.425	2.617	0.079	0.0577	33.2	1729	1969	2472	0.71	"	tos washer-type in-
"	3	58	"	-3.38	-2.50	8.30	175	174	79	70	7.30	1.65	2.402	2.567	0.069	0.0575	32.7	1705	2100	2607	0.62	"	sulator vice lava
4-25	11	103	30.51	-4.04	-3.20	8.95	174	174	78	68	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1921	2424	1.05	yes	New insulators
"	12	67	"	-4.86	-4.05	7.60	174	174	78	70	13.00	4.95	2.250	2.745	0.220	0.0575	35.0	1828	1961	2465	1.98	"	
"	15	150	"	-4.96	-4.20	7.50	174	174	79	71	13.45	5.22	2.230	2.752	0.234	0.0575	35.0	1828	1991	2496	2.10	"	New insulators
"	16	-	"	-5.07	-4.35	7.30	174	174	79	69	13.90	5.48	2.200	2.748	0.249	0.0575	35.0	1828	2016	2521	2.24	"	
"	17	-	"	-5.16	-4.50	7.15	174	174	79	70	14.40	5.77	2.160	2.737	0.267	0.0576	34.8	1813	2041	2548	2.40	"	
"	18	-	"	-4.00	-3.20	9.00	174	179	79	68	9.00	2.60	2.470	2.730	0.105	0.0575	34.8	1818	1922	2425	0.95	"	
"	19	-	"	-4.00	-3.15	8.95	174	178	79	69	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1922	2425	1.05	"	

TABLE III

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-25	23	-	30.51	-4.04	-1.75	27.25	174	174	79	71	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	1996	2500	0.97	yes	
"	24	-	"	-4.04	-1.80	27.25	174	175	79	71	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	1961	2465	0.97	no	Insulator in flow
"	25	-	"	-4.04	-1.75	27.25	174	174	79	76	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	1988	2494	0.97	yes	New insulators
"	26	-	"	-4.04	-1.75	27.25	174	174	79	69	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	1987	2493	0.97	"	Demonstration run
"	27	-	"	-4.04	-1.75	27.25	174	174	79	71	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	1987	2493	0.97	"	" "
"	28	-	"	-8.26	-6.25	22.75	174	174	79	69	11.30	3.97	3.670	4.067	0.108	0.0483	61.6	3825	2009	2514	0.97	"	
"	29	-	"	-8.26	-6.30	22.75	172	172	79	70	11.30	3.97	3.660	4.051	0.108	0.0485	61.4	3800	2005	2510	0.97	"	
"	30	-	"	-8.26	-6.30	22.75	174	174	79	70	11.30	3.97	3.660	4.057	0.108	0.0483	61.5	3818	2006	2511	0.97	"	
"	31	79	"	-8.26	-6.30	22.75	173	172	79	70	11.30	3.97	3.660	4.057	0.108	0.0484	61.5	3810	2004	2509	0.97	"	
4-26	1	77	30.26	-8.00	-6.00	22.75	174	174	77	72	11.30	3.97	3.670	4.067	0.108	0.0483	61.6	3825	2008	2512	0.97	yes	
"	5	97	"	-3.79	-1.50	27.30	174	174	78	69	12.60	4.72	4.360	4.832	0.108	0.0575	61.5	3210	1988	2494	0.97	"	

TABLE II

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-12	17	98	29.76	-3.29	-1.60	18.70	174	174	83	67	11.20	3.92	3.270	3.962	0.110	0.0575	50.5	2635	1973	2477	0.99	yes	
"	18	-	"	-3.29	-1.60	18.70	174	182	83	65	11.20	3.92	3.270	3.962	0.110	0.0575	50.5	2635	1964	2467	0.99	"	
"	19	-	"	-3.38	-1.80	18.40	174	174	83	69	11.90	4.31	3.530	3.961	0.112	0.0575	50.5	2635	1950	2453	1.10	no	Reading low hot spot
"	20	-	"	-3.29	-1.60	18.70	178	178	83	76	11.20	3.92	3.570	3.962	0.110	0.0571	50.9	2673	1951	2454	0.99	"	Temperature position
"	21	52	29.74	-3.51	-1.90	18.00	176	174	83	67	12.90	4.91	3.490	3.981	0.141	0.0573	51.0	2665	1953	2457	1.27	"	
4-15	4	74	30.28	-3.82	-2.15	18.70	175	174	79	70	11.20	3.92	3.580	3.972	0.109	0.0573	50.7	2652	1955	2459	0.98	no	Insulator in flow
4-17	1	106	30.21	-3.74	-2.10	18.70	179	174	79	70	11.20	3.92	3.570	3.962	0.110	0.0571	50.9	2670	1970	2473	0.99	yes	
"	2	-	"	-3.74	-2.10	18.70	176	174	79	68	11.20	3.92	3.570	3.962	0.110	0.0573	50.7	2655	1966	2469	0.99	"	
"	3	-	"	-4.03	-2.50	17.70	176	174	79	69	13.20	5.09	3.458	3.967	0.147	0.0572	50.7	2660	1962	2465	1.32	"	
"	4	-	"	-4.13	-2.60	17.30	174	174	79	71	13.90	5.48	3.420	3.968	0.160	0.0574	50.7	2648	1968	2471	1.44	"	
"	5	-	"	-4.26	-2.75	16.95	174	176	79	69	14.60	5.88	3.380	3.968	0.174	0.0575	50.6	2640	1968	2471	1.57	"	New insulators
"	6	60	"	-4.37	-2.85	16.60	175	174	80	70	15.30	6.27	3.335	3.962	0.188	0.0575	50.5	2632	1992	2496	1.69	"	
"	7	98	"	-3.74	-2.10	18.70	174	174	80	70	11.20	3.92	3.564	3.962	0.110	0.0575	50.5	2632	1965	2468	0.99	"	New insulators
"	8	-	"	-4.26	-2.75	16.95	178	201	80	70	14.60	5.88	3.376	3.964	0.174	0.0571	50.9	2672	1975	2479	1.57	"	
"	9	-	"	-4.26	-2.75	16.95	178	174	80	70	14.60	5.88	3.376	3.964	0.174	0.0571	50.9	2672	1996	2500	1.57	"	New insulators
"	10	47	"	-4.37	-2.85	16.60	177	174	80	70	15.30	6.27	3.335	3.962	0.188	0.0572	50.7	2662	2022	2528	1.69	"	
4-18	1	174	30.37	-3.90	-2.30	18.70	174	175	80	67	11.20	3.92	3.572	3.964	0.110	0.0575	50.5	2534	1971	2474	0.99	no	
"	2	-	"	-4.30	-2.70	17.30	174	175	80	71	13.90	5.48	3.420	3.968	0.160	0.0574	50.7	2648	2012	2516	1.44	"	
"	3	52	"	-4.41	-2.90	16.95	174	174	80	70	14.60	5.88	3.379	3.967	0.174	0.0575	50.5	2638	2000	2504	1.57	"	Insulator in flow
"	4	95	"	-4.20	-2.60	17.70	174	174	80	65	13.20	5.09	3.460	3.969	0.147	0.0575	50.6	2641	1968	2471	1.32	yes	New insulators
"	5	-	"	-4.29	-2.70	17.30	174	174	80	68	13.90	5.48	3.420	3.968	0.160	0.0574	50.7	2648	1978	2482	1.44	"	
"	6	-	"	-4.42	-2.90	16.95	174	174	80	68	14.60	5.88	3.379	3.967	0.174	0.0574	50.6	2647	2000	2504	1.57	"	
"	7	-	"	-4.53	-3.10	16.60	174	174	80	70	15.30	6.27	3.330	3.957	0.188	0.0574	50.5	2639	2032	2537	1.69	"	
"	8	84	"	-4.20	-2.60	17.70	174	174	80	68	13.20	5.09	3.460	3.969	0.147	0.0574	50.7	2649	1968	2471	1.32	"	New insulators
"	9	-	"	-3.99	-2.40	18.40	174	174	80	71	11.90	4.31	3.542	3.973	0.122	0.0574	50.7	2650	1972	2475	1.10	"	
"	10	-	"	-4.12	-2.50	18.00	175	174	80	71	12.60	4.71	3.500	3.971	0.135	0.0572	50.8	2665	1974	2477	1.21	"	
"	11	81	"	-4.19	-2.60	17.70	174	174	80	70	13.20	5.09	3.460	3.969	0.147	0.0574	50.7	2649	1970	2473	1.32	"	New insulators
"	12	-	"	-3.80	-2.10	19.05	174	174	81	74	10.55	3.53	3.624	3.977	0.097	0.0573	50.8	2660	1968	2471	0.87	"	
"	13	71	"	-3.68	-2.00	19.40	174	174	81	72	9.90	3.15	3.662	3.977	0.086	0.0575	50.6	2642	1968	2471	0.77	"	
"	14	-	"	-3.68	-2.00	19.40	174	174	81	70	9.90	3.15	3.662	3.977	0.086	0.0575	50.6	2642	1963	2466	0.77	"	
"	15	64	"	-3.80	-2.10	19.05	174	174	81	70	10.55	3.53	3.624	3.977	0.097	0.0573	50.8	2661	1969	2472	0.87	"	
"	16	118	"	-3.90	-2.30	18.70	174	174	79	69	11.20	3.92	3.585	3.977	0.109	0.0575	50.6	2642	1964	2467	0.98	"	Side insulator broke
"	17	-	"	-3.55	-1.80	19.75	174	174	79	76	9.25	2.75	3.710	3.985	0.074	0.0575	50.8	2652	-	-	0.67	no	No ignition - 2280°F
"	18	-	"	-3.68	-2.00	19.40	174	175	80	74	9.90	3.15	3.662	3.677	0.086	0.0575	50.6	2642	1965	2468	0.77	yes	
"	19	67	"	-3.61	-1.90	19.55	174	174	80	74	9.60	2.94	3.688	3.982	0.080	0.0575	50.8	2648	2076	2581	0.72	"	

TABLE II (cont)

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/a_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-18	20	-	30.37	-3.68	-2.00	19.40	174	174	80	76	9.90	3.15	3.662	3.977	0.086	0.0575	50.6	2642	1965	2468	0.77	yes	
"	21	-	"	-3.60	-1.90	19.55	174	174	80	68	9.60	2.94	3.688	3.982	0.080	0.0575	50.8	2648	2018	2522	0.72	"	
"	22	60	"	-3.65	-1.95	19.50	174	174	80	65	9.75	3.03	3.675	3.978	0.083	0.0575	50.7	2645	2020	2524	0.75	"	
4-25	1	132	30.51	-4.04	-2.40	13.70	174	174	77	68	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	1972	2477	0.99	yes	
"	5	-	"	-4.10	-2.50	18.50	174	174	77	69	11.50	4.10	3.560	3.970	0.115	0.0575	50.6	2642	1969	2474	1.04	"	
"	6	-	"	-4.13	-2.55	18.40	174	174	77	70	11.90	4.32	3.560	3.992	0.121	0.0575	50.9	2655	1964	2469	1.09	"	
"	7	-	"	-4.21	-2.60	18.15	174	174	77	71	12.20	4.50	3.520	3.972	0.128	0.0574	50.7	2650	1962	2467	1.15	"	
"	8	-	"	-4.26	-2.65	18.00	174	174	78	71	12.60	4.72	3.510	3.992	0.134	0.0573	51.0	2670	1961	2465	1.21	"	

TABLE IV

Test Data

Date	Run	Leak Test	Barom	p_o	p_1	Δp	T_o	T_n	T_1	T_f	Roto	w_f	w_a	w	w_f/w_a	ρ_o	V	$V/\rho_o L$	T_{wa}	T_w	$\%w_f/w_a$	Plot	Remarks
1957		sec	" Hg	" Hg	" Hg	" H_2O	°F	°F	°F	°F		#/sec x10^{+4}	#/sec x10^{+3}	#/sec x10^{+3}		#/ft^3	fps		°F	°R			
4-25	2	-	30.51	-4.04	-2.40	18.70	174	120	77	67	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	2005	2510	0.99	yes	
"	3	-	"	-4.04	-2.40	18.70	174	119	77	66	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	2005	2510	0.99	"	
"	4	-	"	-4.04	-2.40	18.70	174	121	77	68	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	2008	2513	0.99	"	
"	9	-	"	-4.04	-2.40	18.70	174	121	78	70	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	2010	2515	0.99	"	
"	10	56	"	-4.04	-2.40	18.70	174	116	78	70	11.20	3.91	3.540	3.931	0.110	0.0575	50.1	2615	2003	2508	0.99	"	
"	13	110	"	-4.04	-3.15	8.95	174	120	78	70	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1943	2447	1.05	"	New insulators
"	14	71	"	-4.04	-3.15	8.95	174	115	78	69	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1948	2452	1.05	"	
"	20	-	"	-4.04	-3.15	8.95	174	121	79	71	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1936	2439	1.05	"	
"	21	-	"	-4.04	-3.15	8.95	174	110	79	69	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1955	2459	1.05	"	
"	22	-	"	-4.04	-3.15	8.95	174	116	79	70	9.25	2.90	2.470	2.760	0.117	0.0576	35.1	1828	1941	2445	1.05	"	
4-26	2	-	30.26	-8.00	-6.00	22.80	174	112	77	69	11.30	3.97	3.680	4.077	0.108	0.0483	61.7	3830	2056	2564	0.97	yes	
"	3	-	"	-8.00	-6.00	22.75	174	116	77	70	11.30	3.97	3.670	4.067	0.108	0.0483	61.6	3825	2049	2556	0.97	"	
"	4	57	"	-8.00	-6.00	22.75	174	113	77	70	11.30	3.97	3.670	4.067	0.108	0.0483	61.6	3825	2054	2063	0.97	"	
"	6	-	"	-3.80	-1.50	27.20	174	121	79	70	12.60	4.72	4.350	4.822	0.108	0.0575	61.5	3210	2024	2530	0.97	"	
"	7	-	"	-3.80	-1.50	27.30	174	116	79	69	12.60	4.72	4.360	4.832	0.108	0.0575	61.5	3210	2026	2532	0.97	"	
"	8	48	"	-3.80	-1.50	27.40	174	120	79	69	12.60	4.72	4.370	4.842	0.108	0.0575	61.6	3215	2022	2528	0.97	"	

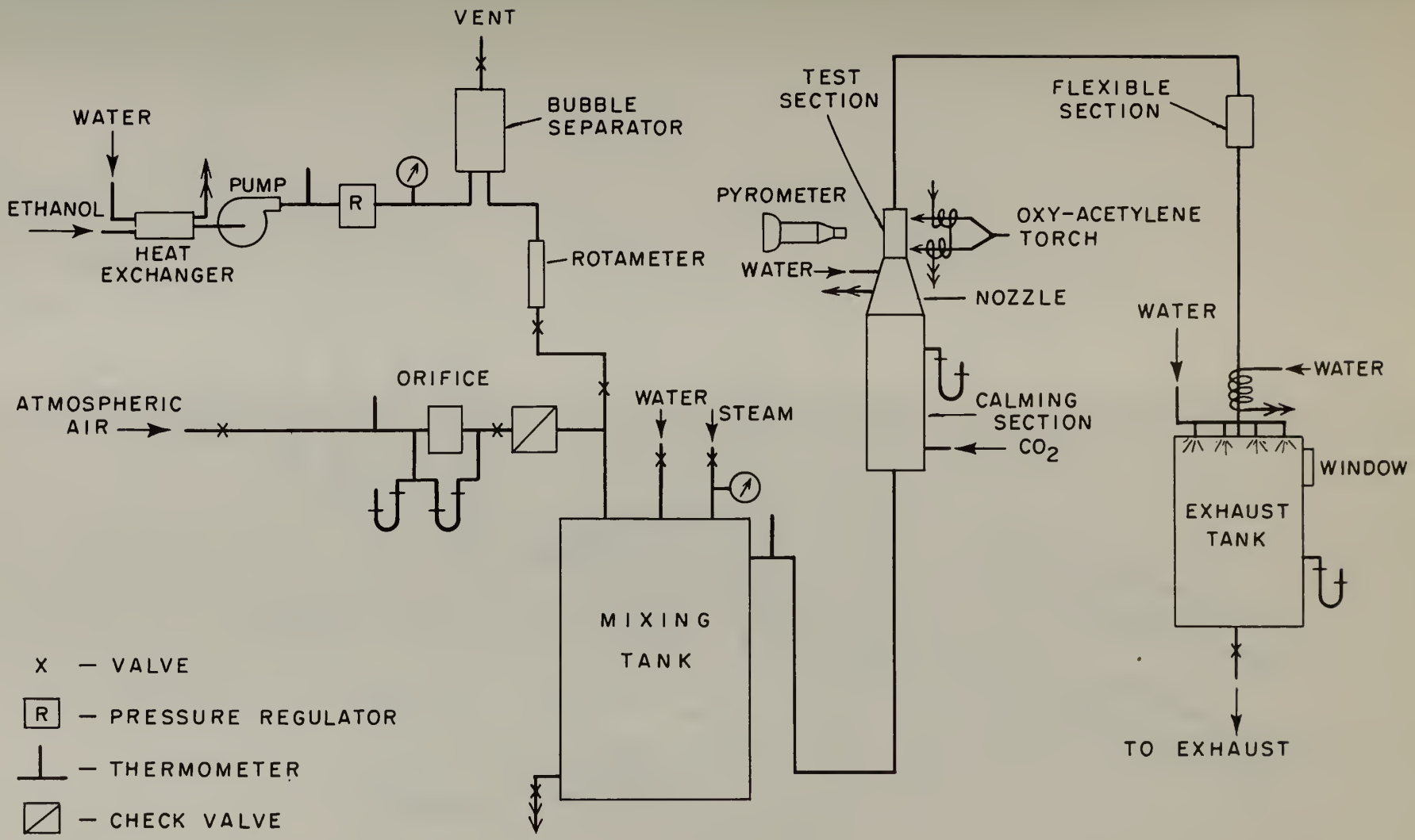


FIG. 1 - SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP

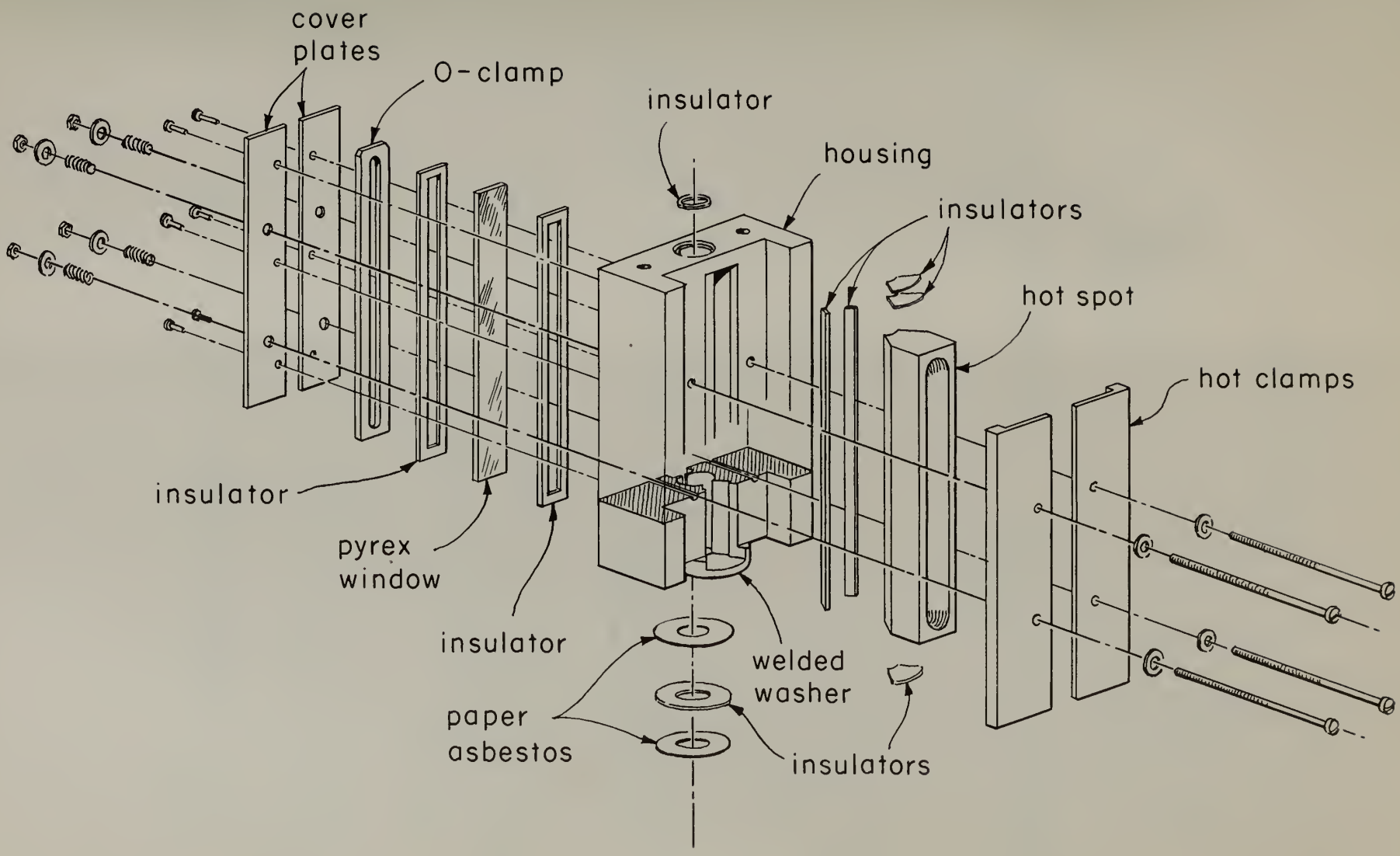
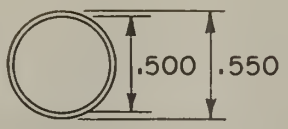
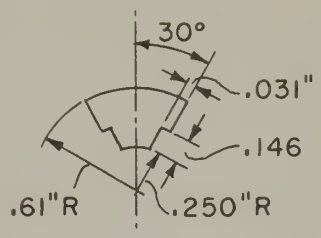


FIG. 2 - TEST SECTION ASSEMBLY

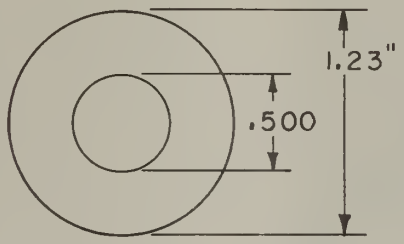
FIG. 3
INSULATORS



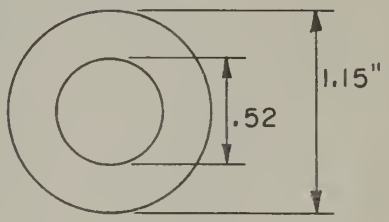
USE 1 - 1/32" THICK RUBBERIZED ASBESTOS - between test section and Vicor tube.



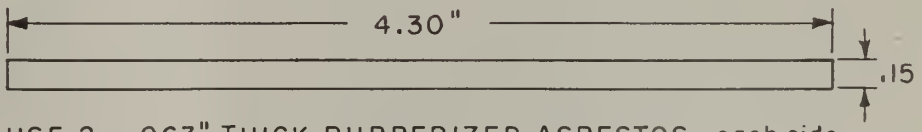
USE 3 - .063" THICK RUBBERIZED ASBESTOS - 2 at top of hot spot 1 at bottom



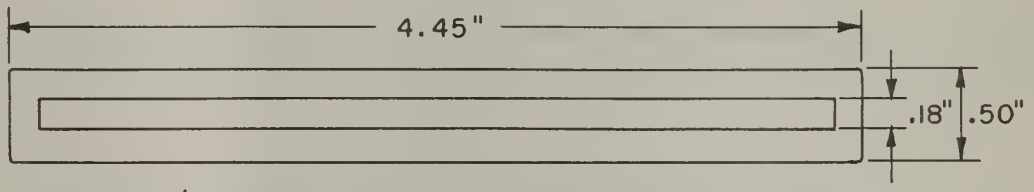
USE 1 - .063" THICK RUBBERIZED ASBESTOS - between nozzle and test section.



USE 2 - .010" THICK PAPER ASBESTOS - each side of rubberized asbestos at left.



USE 2 - .063" THICK RUBBERIZED ASBESTOS - each side of hot spot



USE 2 - 1/32" THICK, RUBBERIZED ASBESTOS - each side of window

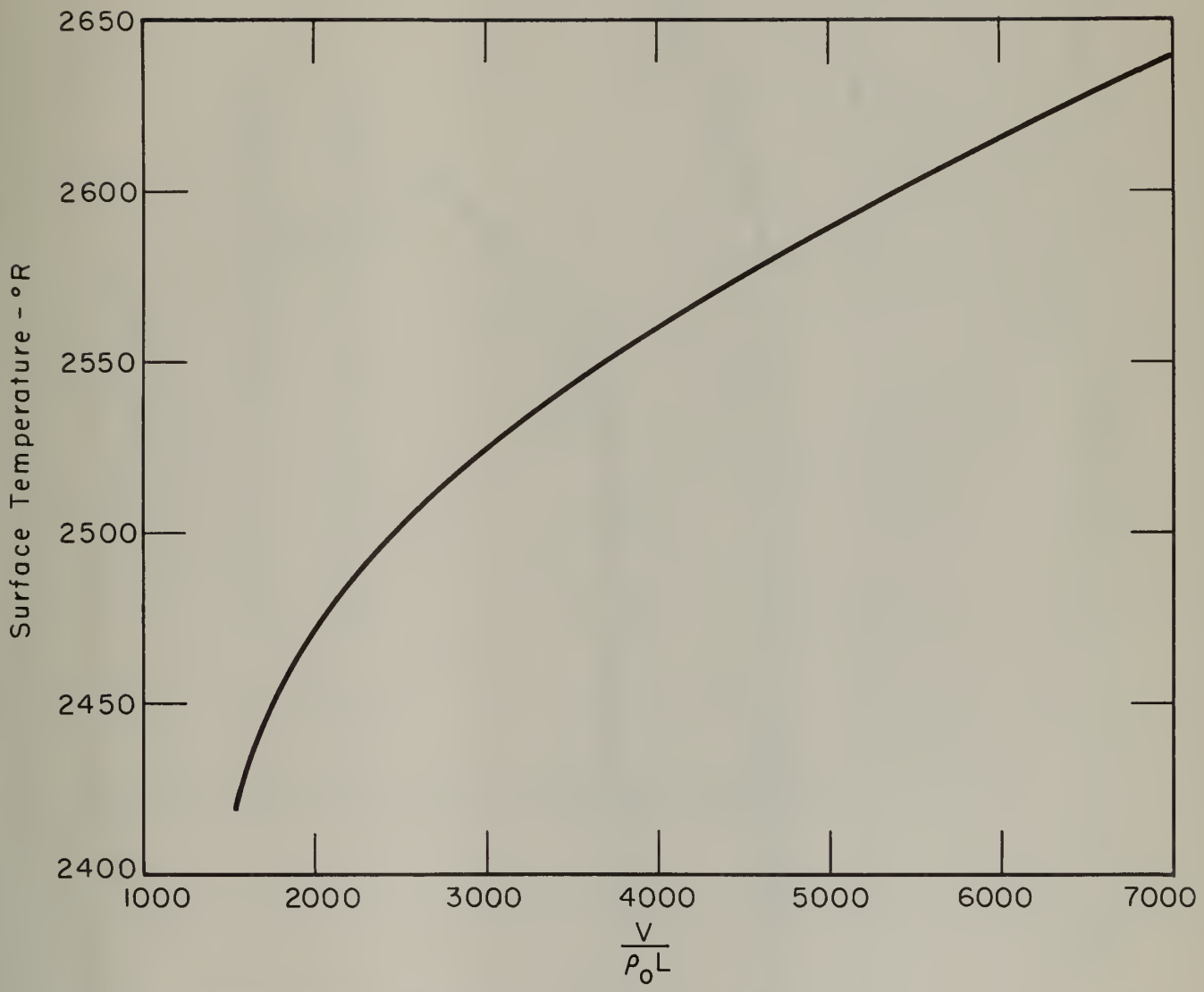


FIG. 4 - RESULTS OF PREVIOUS INVESTIGATIONS AS INTERPRETED BY PROFESSOR T.Y. TOONG

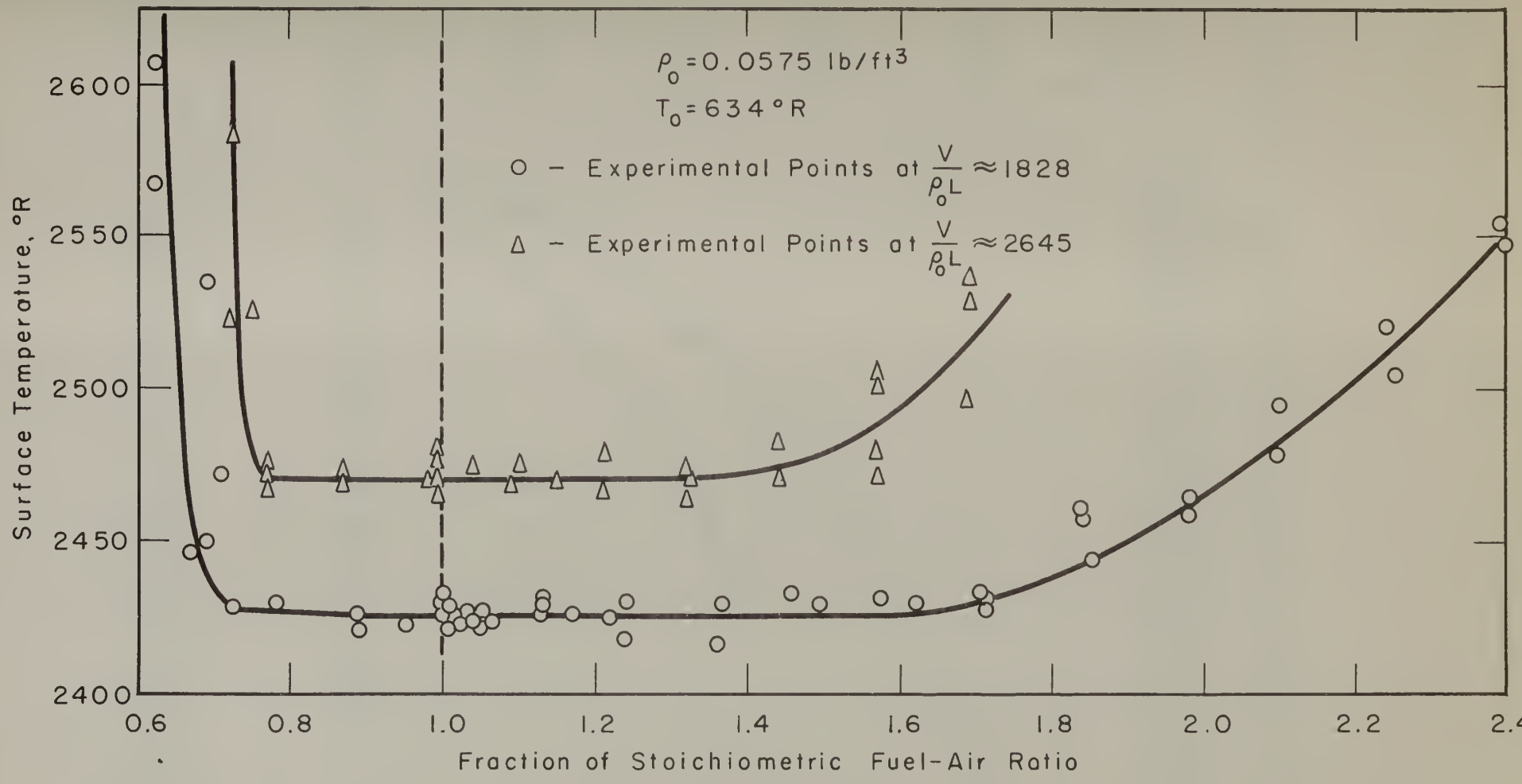


FIG. 5 – EFFECT OF FUEL-AIR RATIO ON TEMPERATURE REQUIRED FOR IGNITION

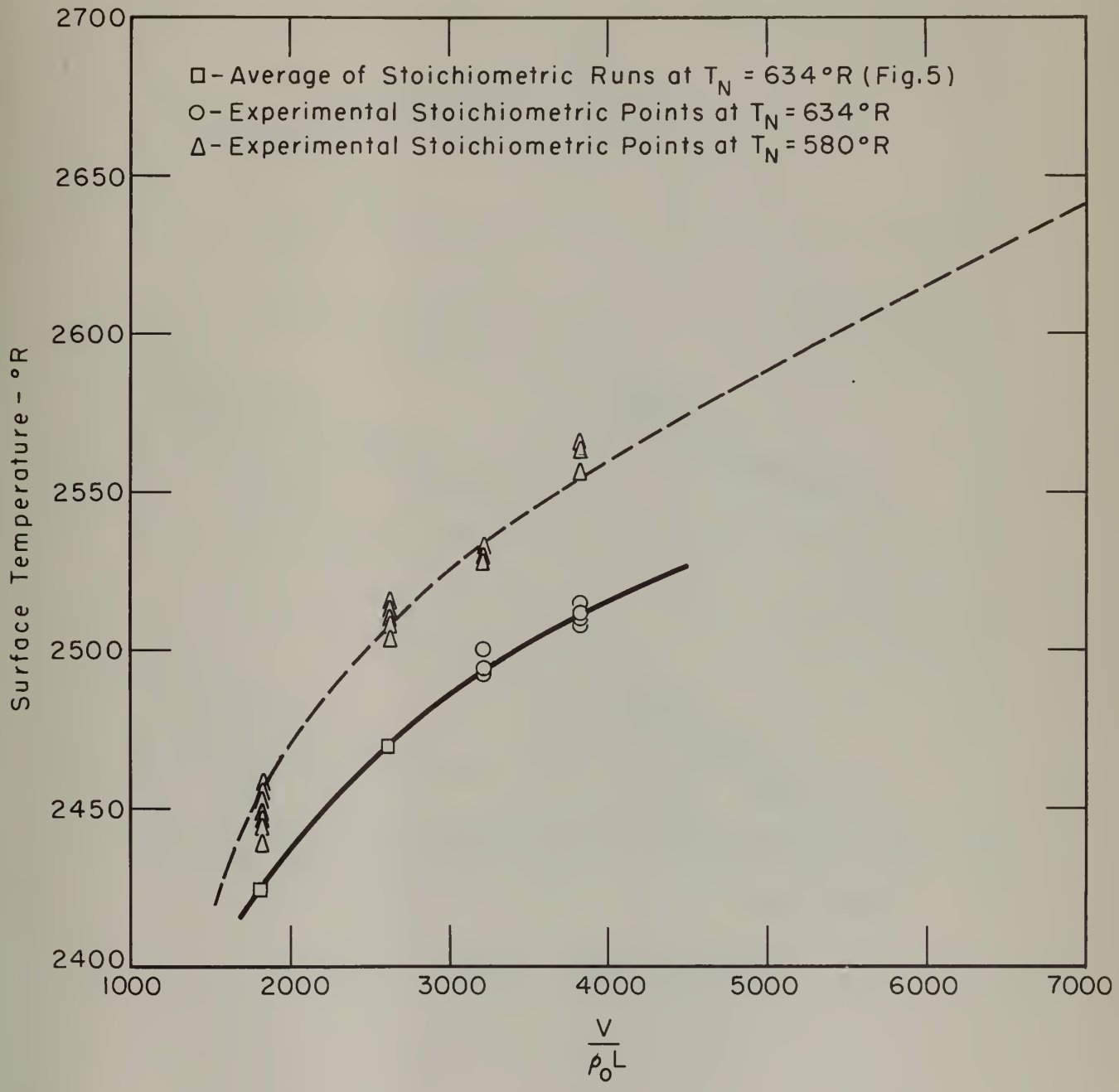


FIG. 6 - EFFECTS OF NOZZLE TEMPERATURE ON TEMPERATURE REQUIRED FOR IGNITION

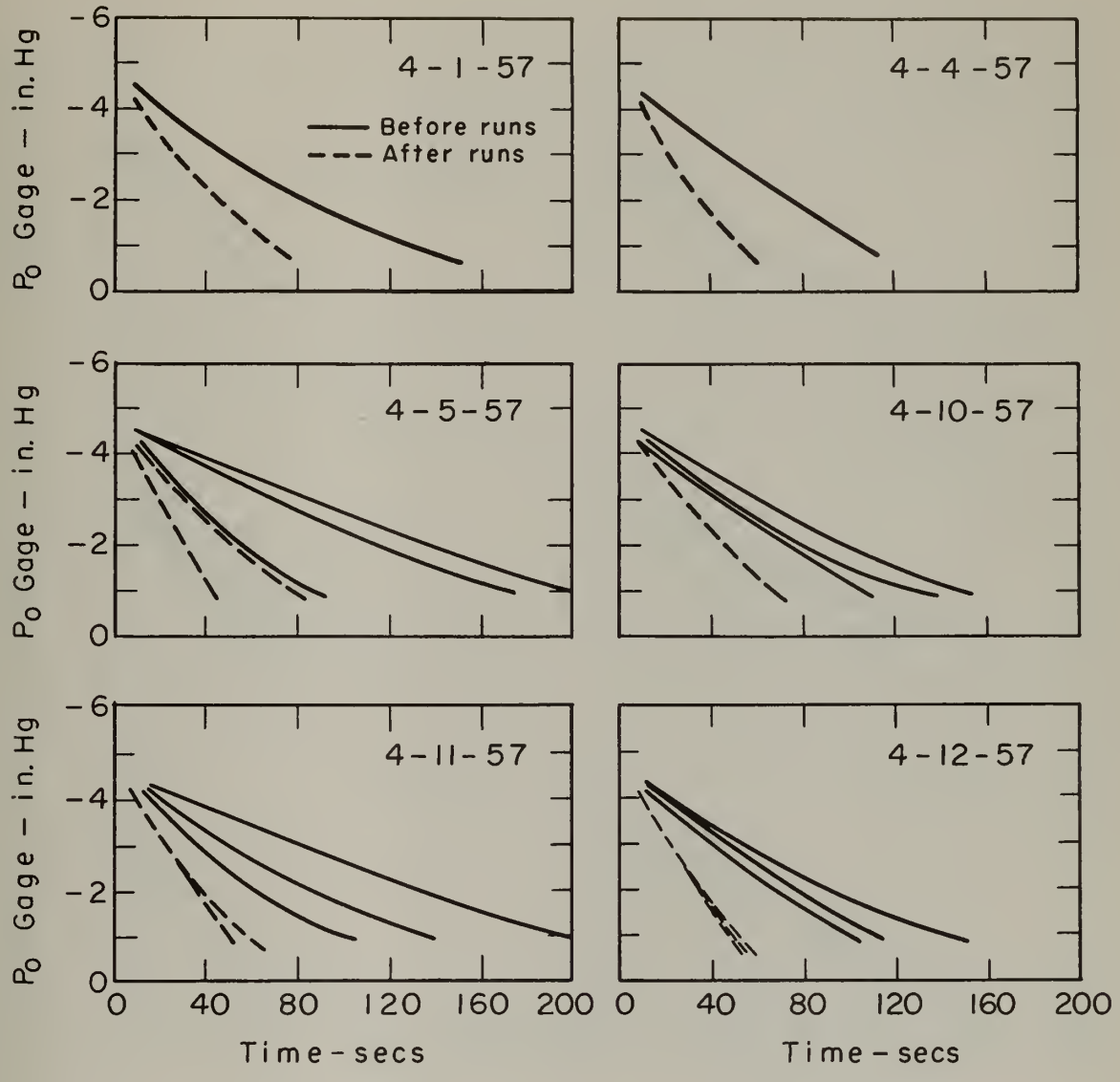


FIG. 7 – LEAK TEST DATA

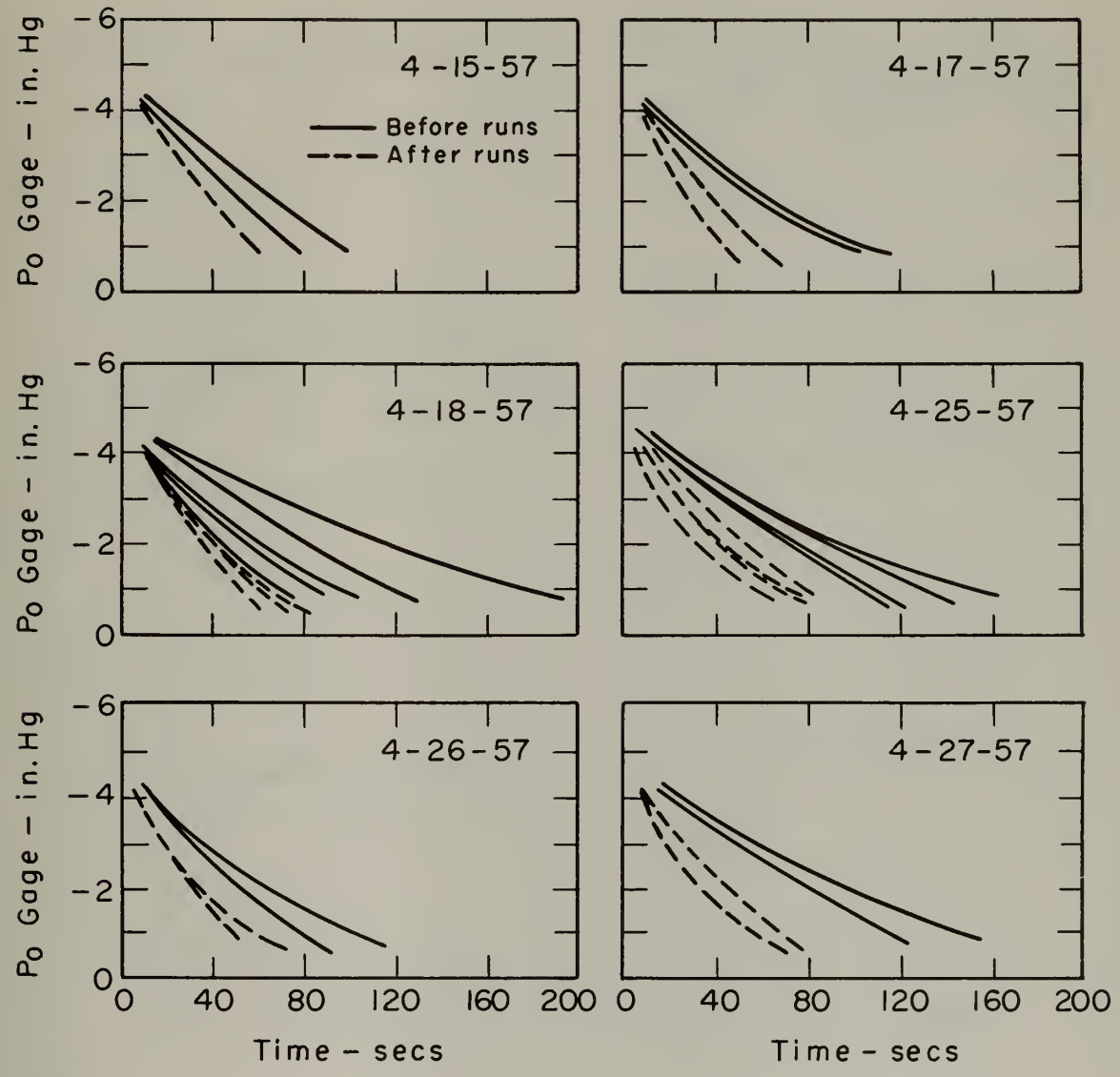


FIG. 8 - LEAK TEST DATA

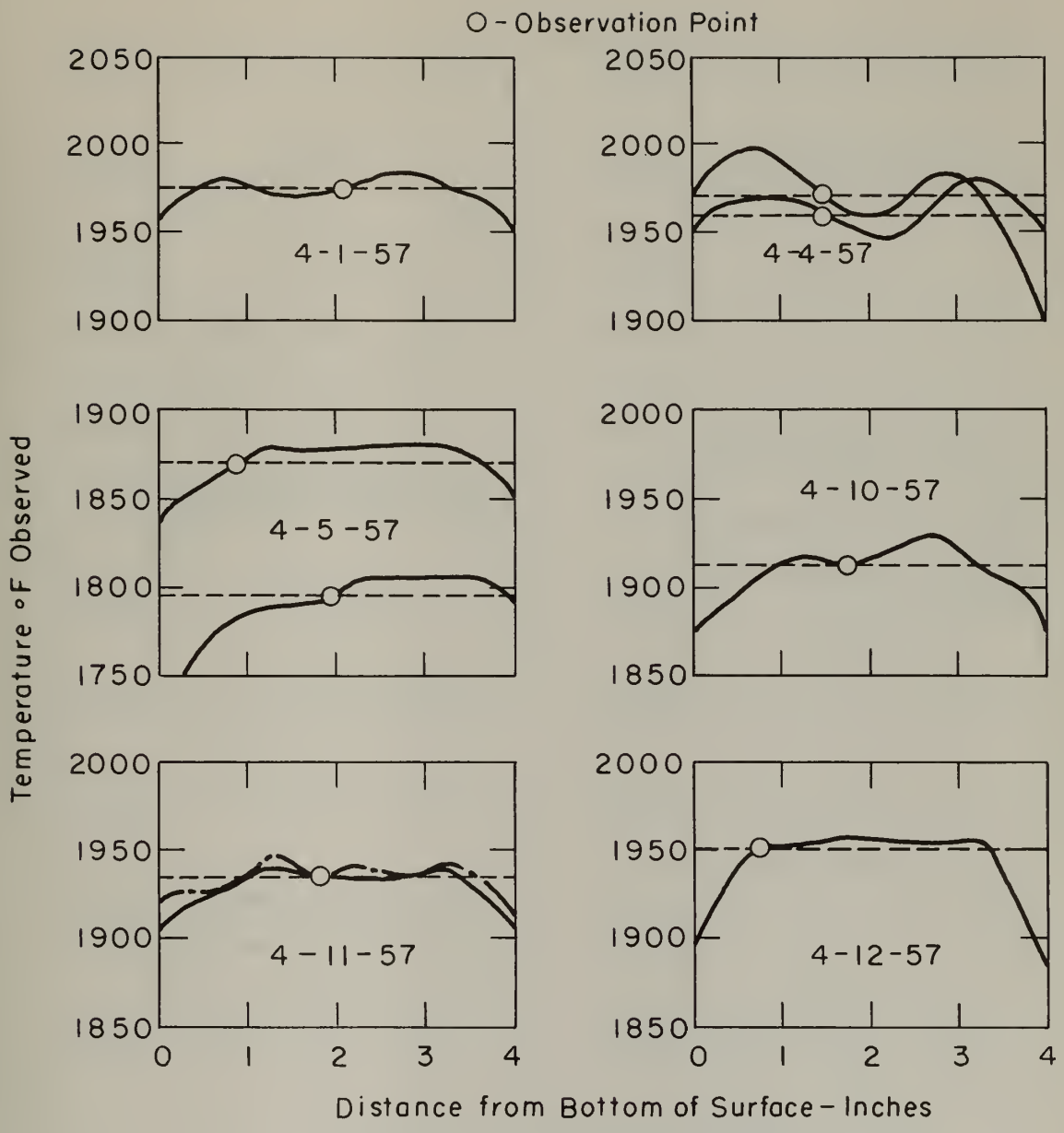


FIG. 9 - TEMPERATURE PROFILES OF HEATED SURFACE

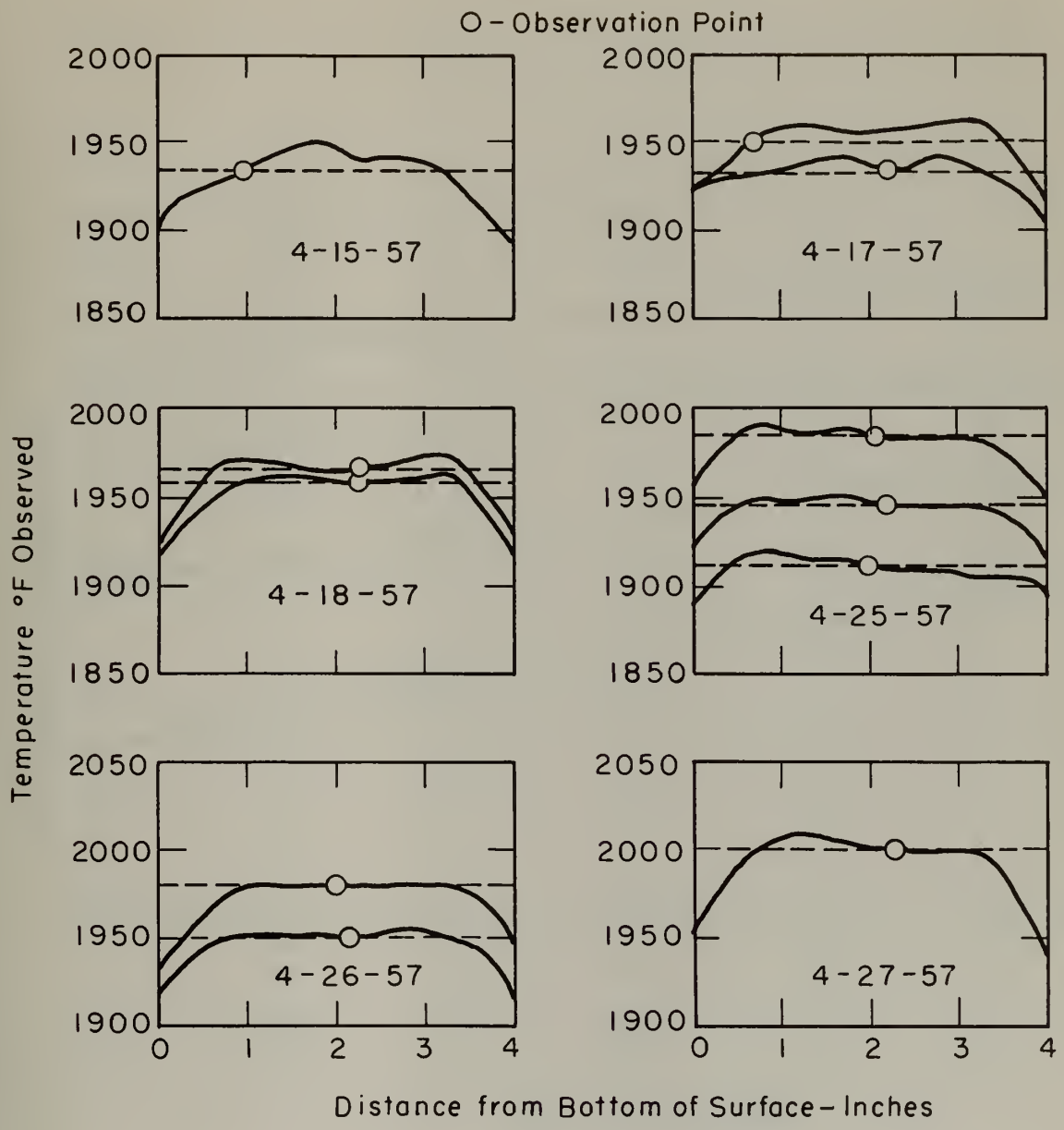


FIG. 10 - TEMPERATURE PROFILES OF HEATED SURFACE

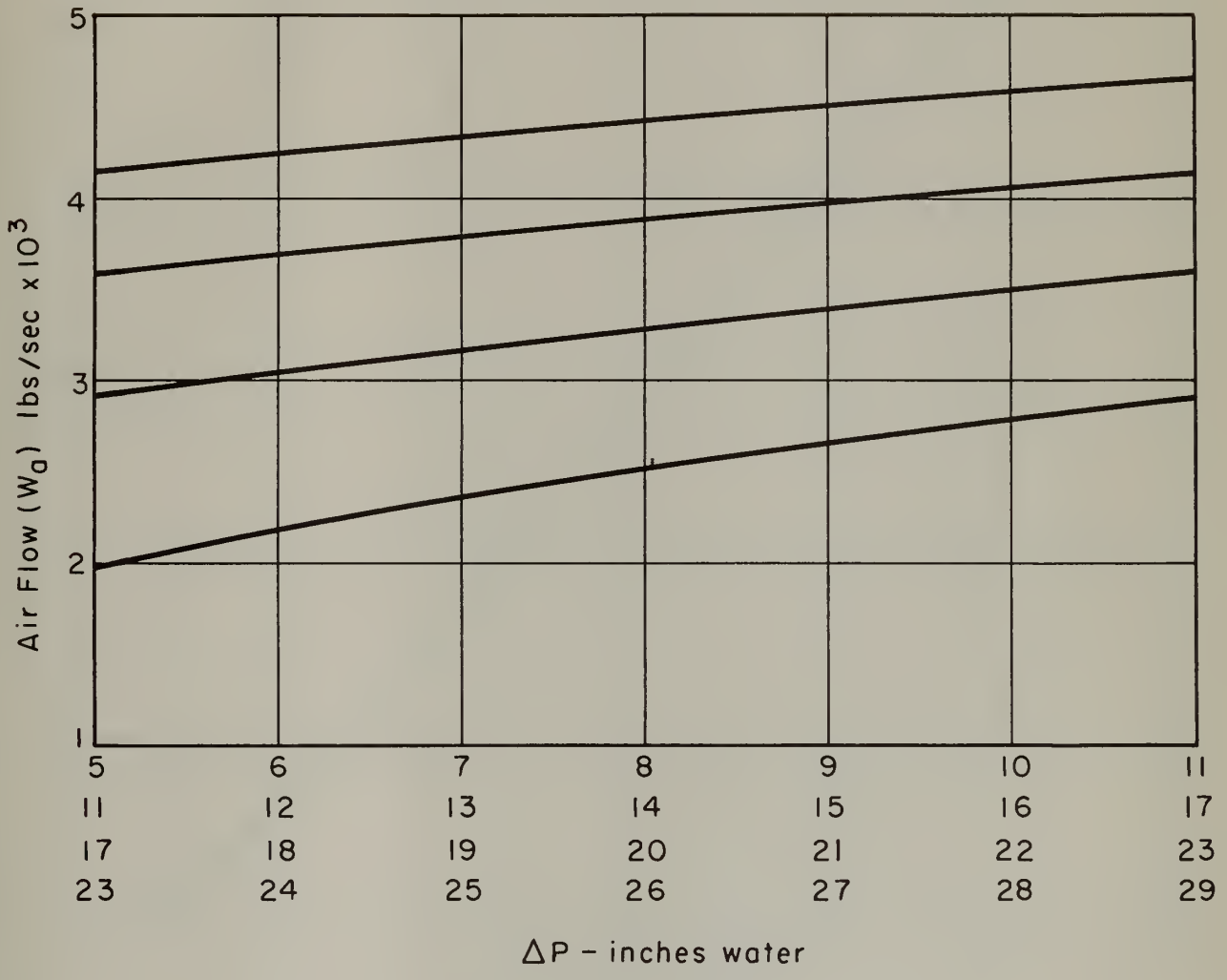


FIG. 11 – 0.230" ORIFICE CALIBRATION

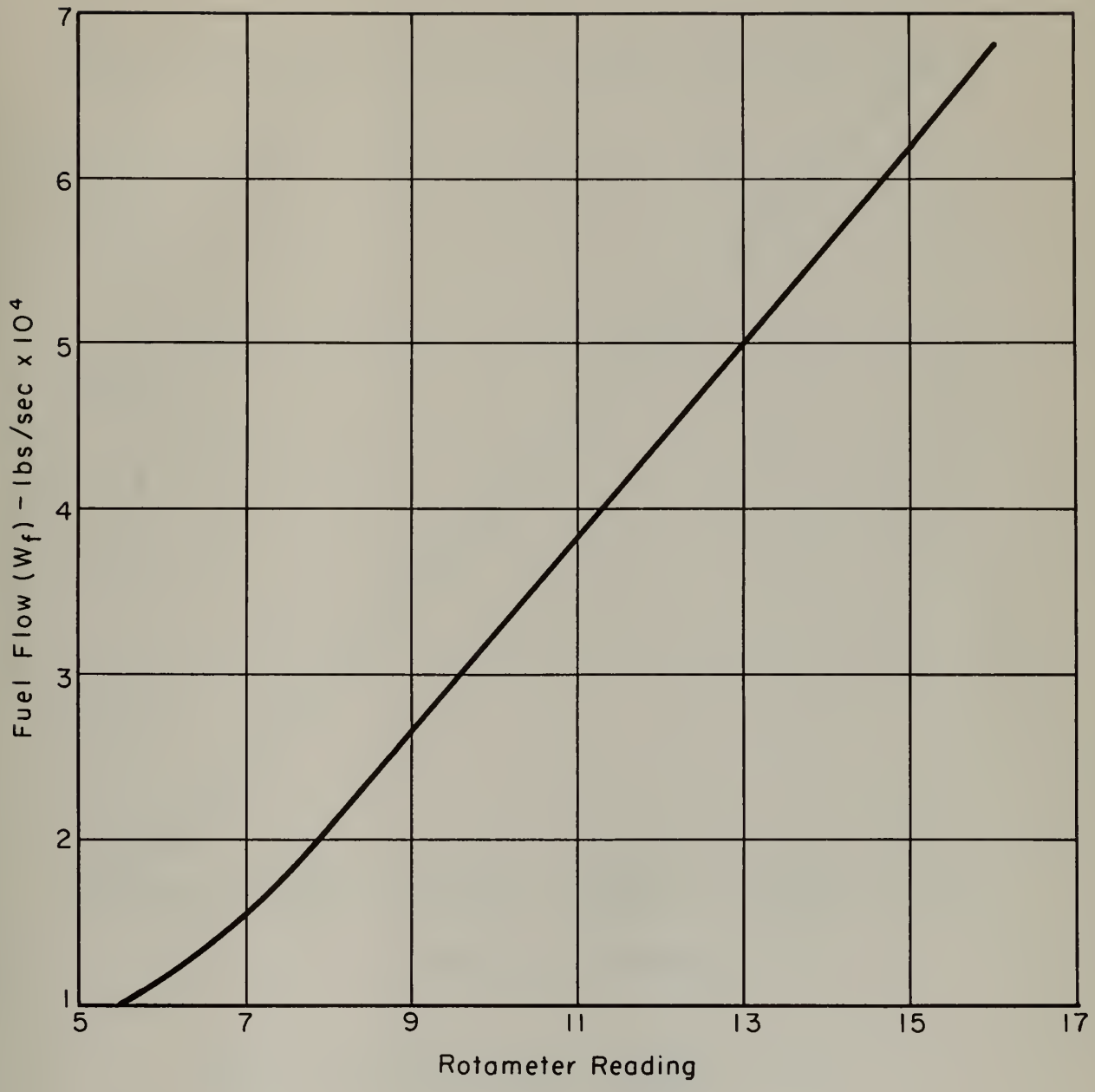


FIG. 12 - ROTAMETER CALIBRATION

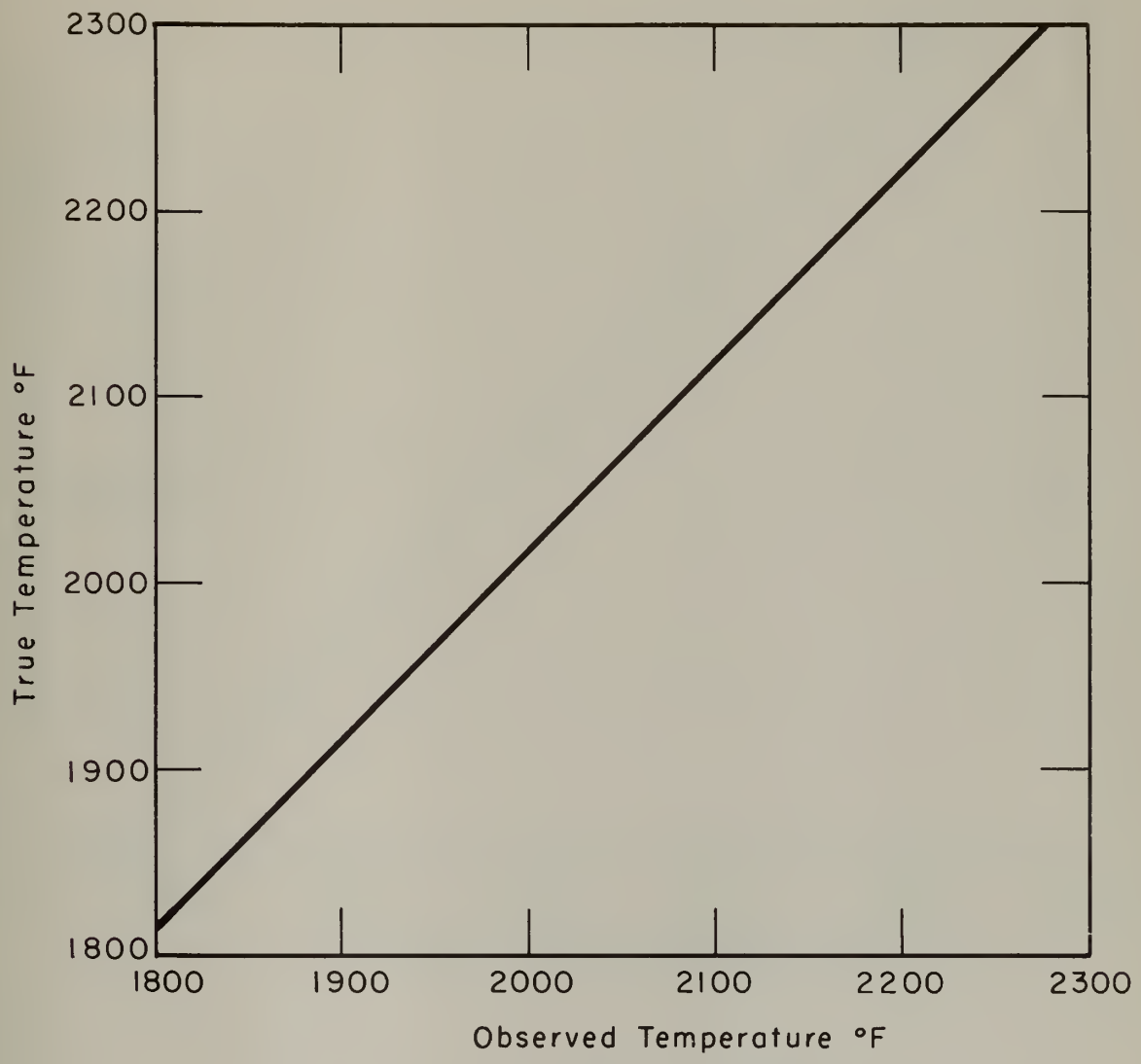


FIG. 13 - EMISSIVITY CORRECTION

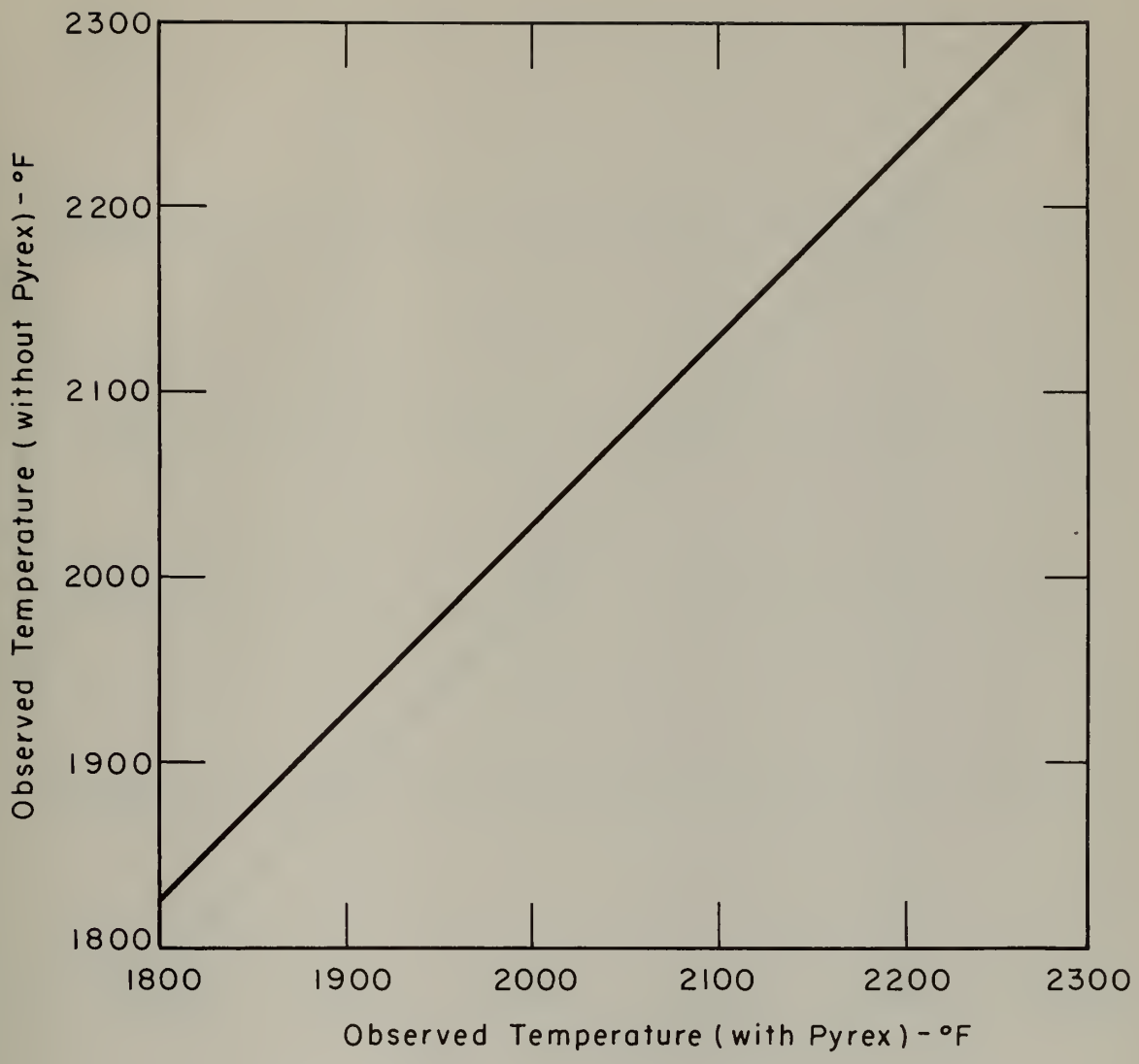


FIG. 14 - PYREX CORRECTION

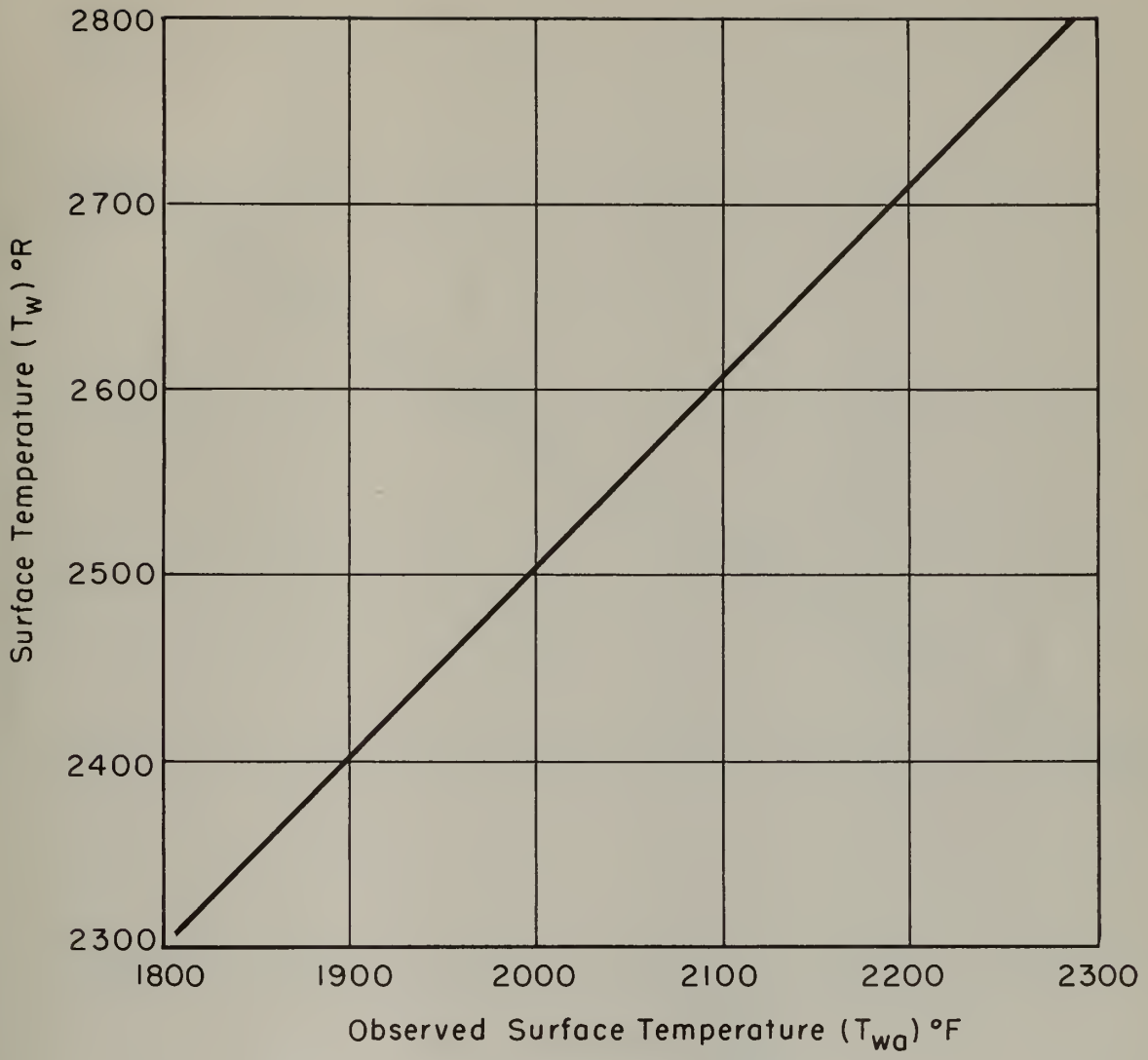


FIG. 15 - TOTAL TEMPERATURE CORRECTION

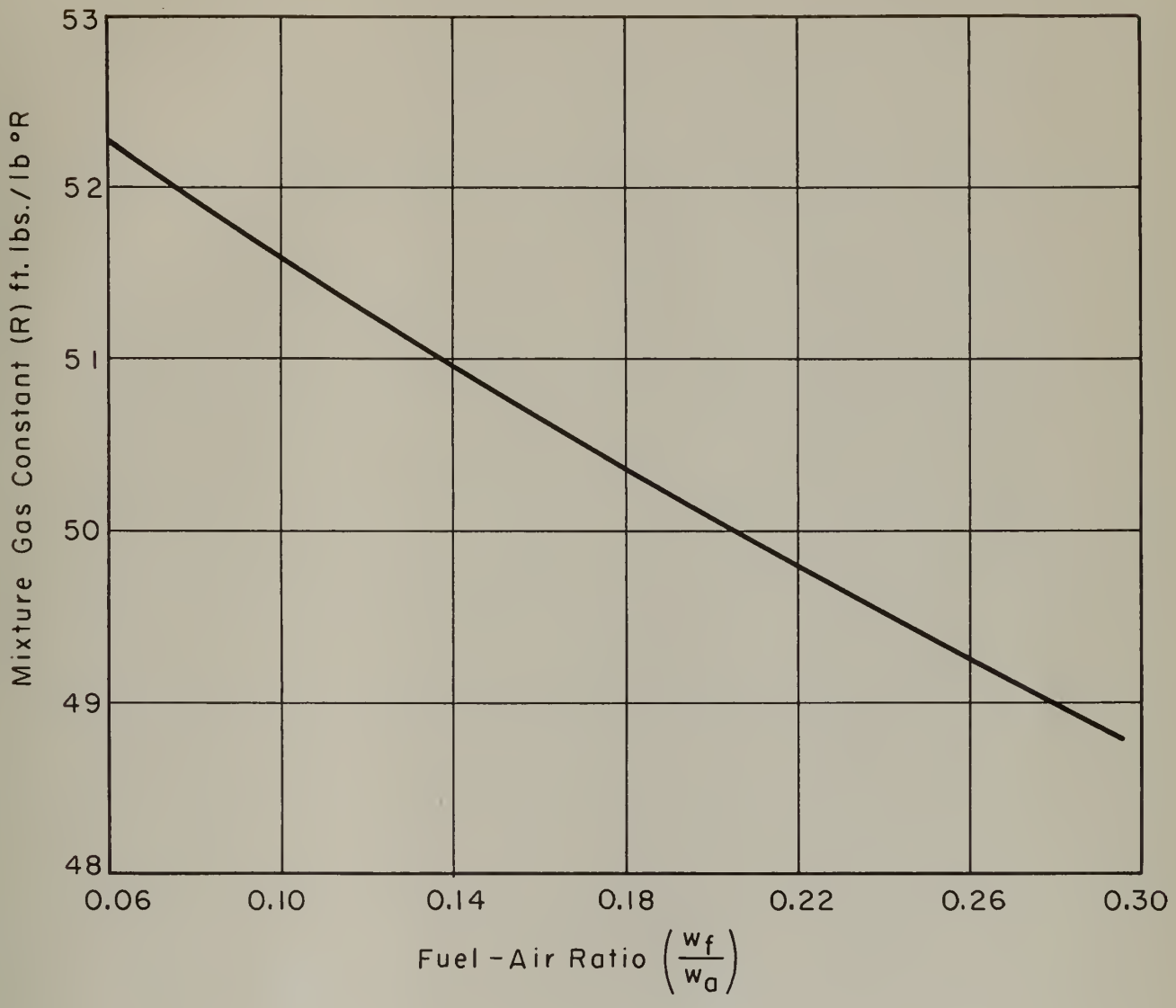


FIG. 16 - MIXTURE GAS CONSTANT vs FUEL AIR RATIO

JA 17 58 BINDERY

Thesis 35890
K3 Kempf
Surface ignition in a steady-flow apparatus.

JA 17 58 BINDERY

Thesis 35890
K3 Kempf
Surface ignition in a steady-flow apparatus.

thesK3
Surface ignition in a steady-flow appara
3 2768 002 12085 9
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